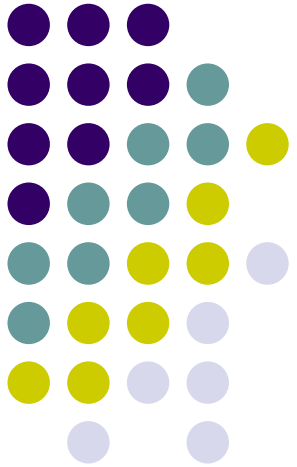
Charmonium Results with BESIII

XXV Rencontres de Physique
de La Vallée d'Aoste
La Thuile 2011, Feb.27-Mar.5, Italy

Dmitry Dedovich (JINR)
on behalf of the BESIII collaboration

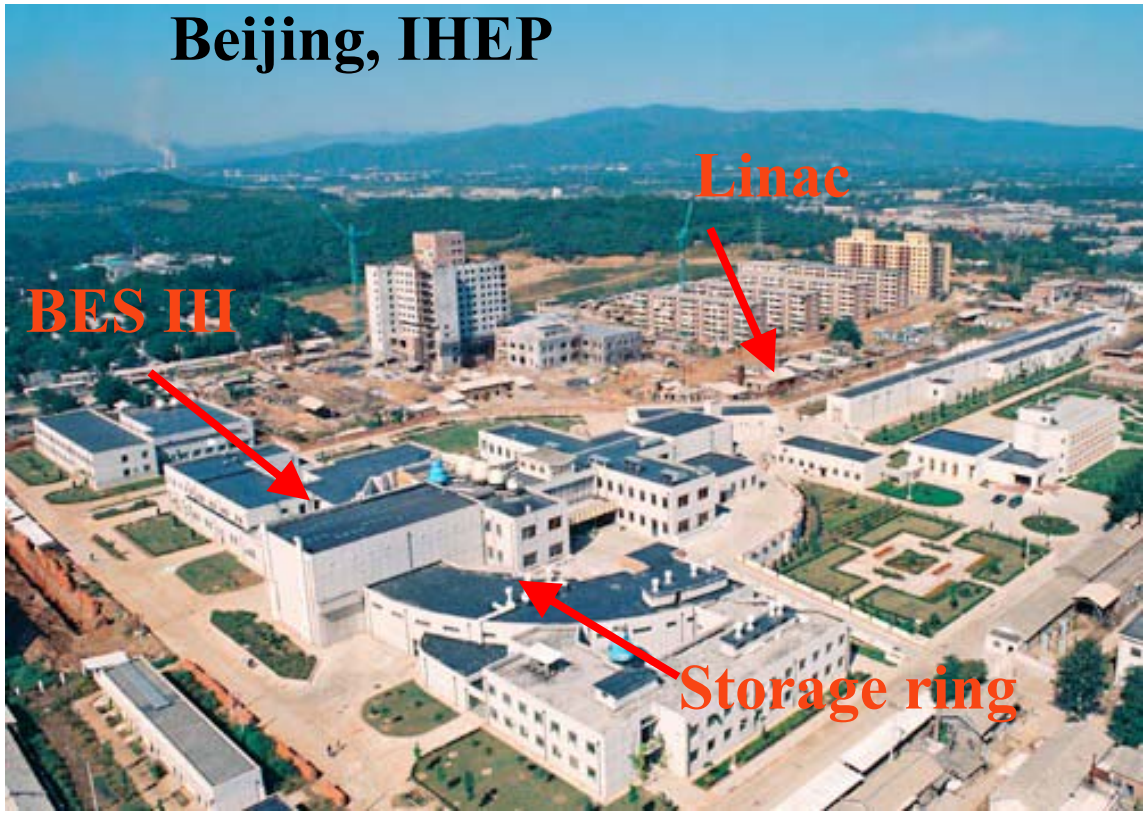


Outlook

- **BEPC II & BES III**
- **Physics results**
  - **h_c**
  - **$\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$**
  - **χ_{cj} decays**
    - **$\chi_{cJ} \to \gamma\varphi, \gamma\omega, \gamma\rho^0$**
    - **$\chi_{cJ} \to \varphi\varphi, \omega\omega, \varphi\omega$**
    - **$\chi_{cJ} \to K^+K^- \pi^+ \pi^-$**
- **Summary**

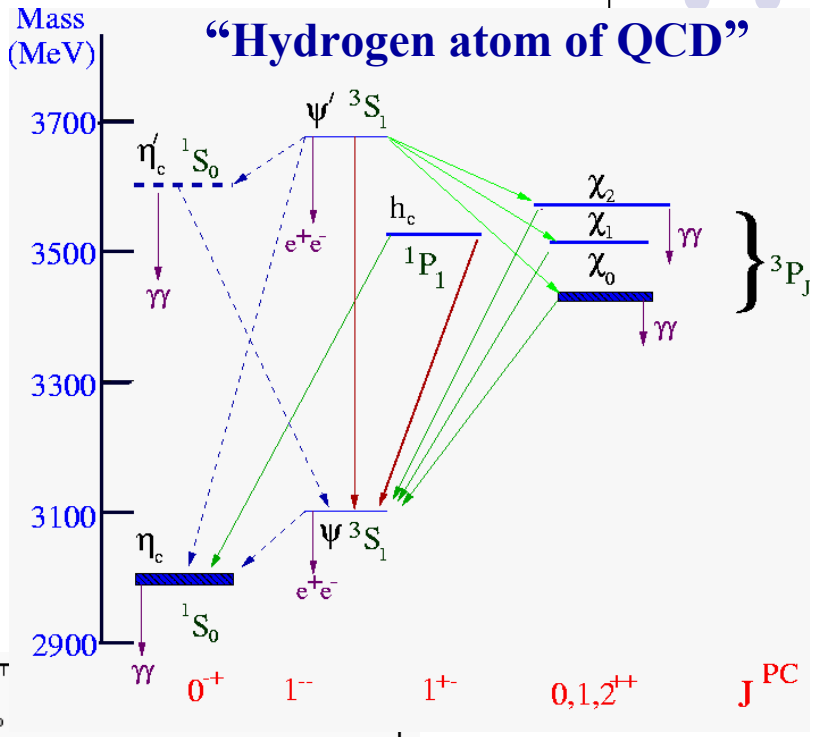
BEPC-II : a high luminosity double-ring collider

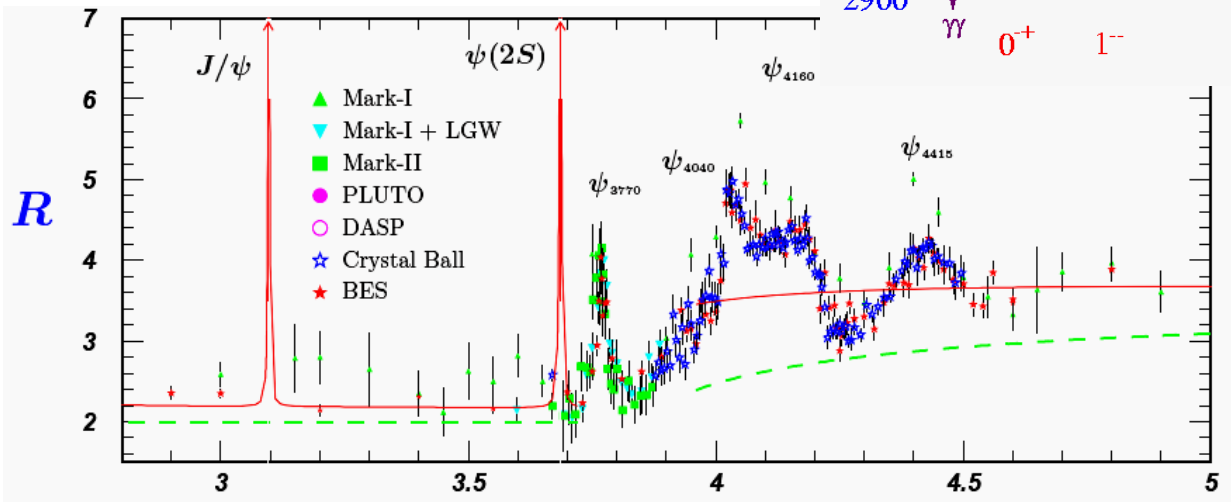
- Beam energy:
  $\sqrt{s}$=2.0 – 4.6 GeV
- Optimum energy:
  $\sqrt{s}$= 3.7 GeV
- Beam crossing angle:22 mrad
- Designed luminosity:1.0×10^{33}
- Record luminosity:
  0.57×10^{33} $cm^{-2}s^{-1}$
- Energy spread: 5.16×10^{-4}



Physics of τ-charm region

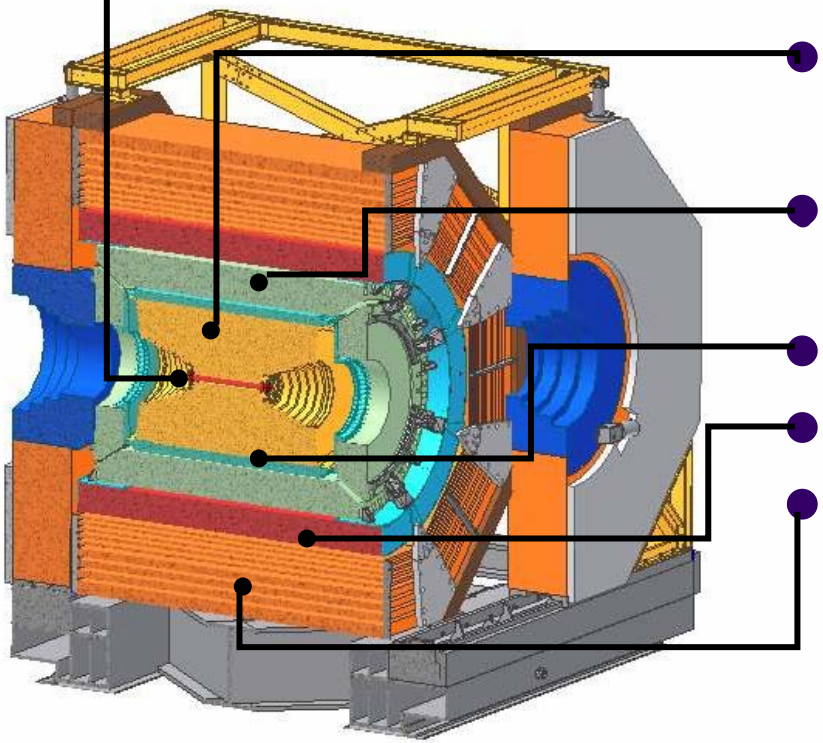
- **Charmonium physics**
  - **Transition & charmonium state**
  - **charmonium decays**
- **Light hadron spectroscopy in J/ψ decay**
  - **enormous statistic, 1^{--} ,λ=±1 initial state**
- **Open charm**
  - **absolute Br, f_D&f_{DS}, CKM, rare decays, D^0-D^0 mixing & CPV,…**
- **τ-lepton mass, R-ratio**
- **Rare & forbidden decay**
- **…**





BES III Detector

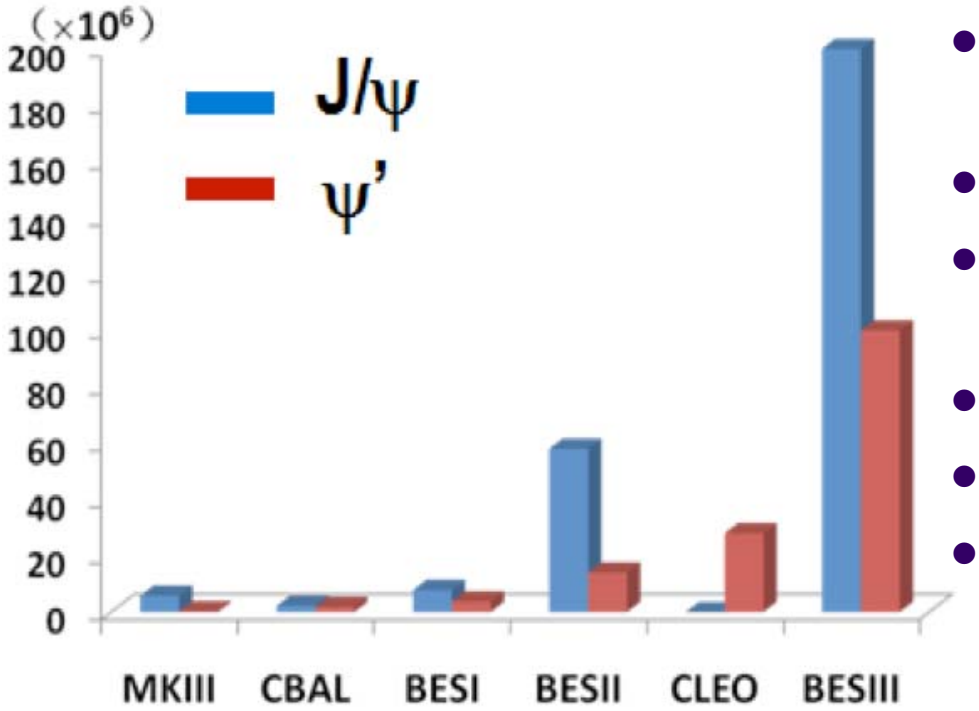
Int. J. Mod. Phys. A24, 377 (2009)
NIM A614, 345 (2010)



- Be beam pipe
- He-based drift chamber:
  δp/p=0.58%, d*E*/d*x*~6% at 1 GeV
- CsI electromagnetic calorimeter:
  δE~2.5%, space 0.6 cm at 1 GeV
- TOF: 80 ps (barrel), 100 ps (endcap)
- 1T Superconducting magnet
- Muon system : 9 layers of RPC in magnet yoke

Close to 4π acceptance(93%), very little material inside tracker, excellent tracking & calorimetry

BEPCII/BESIII Milestones

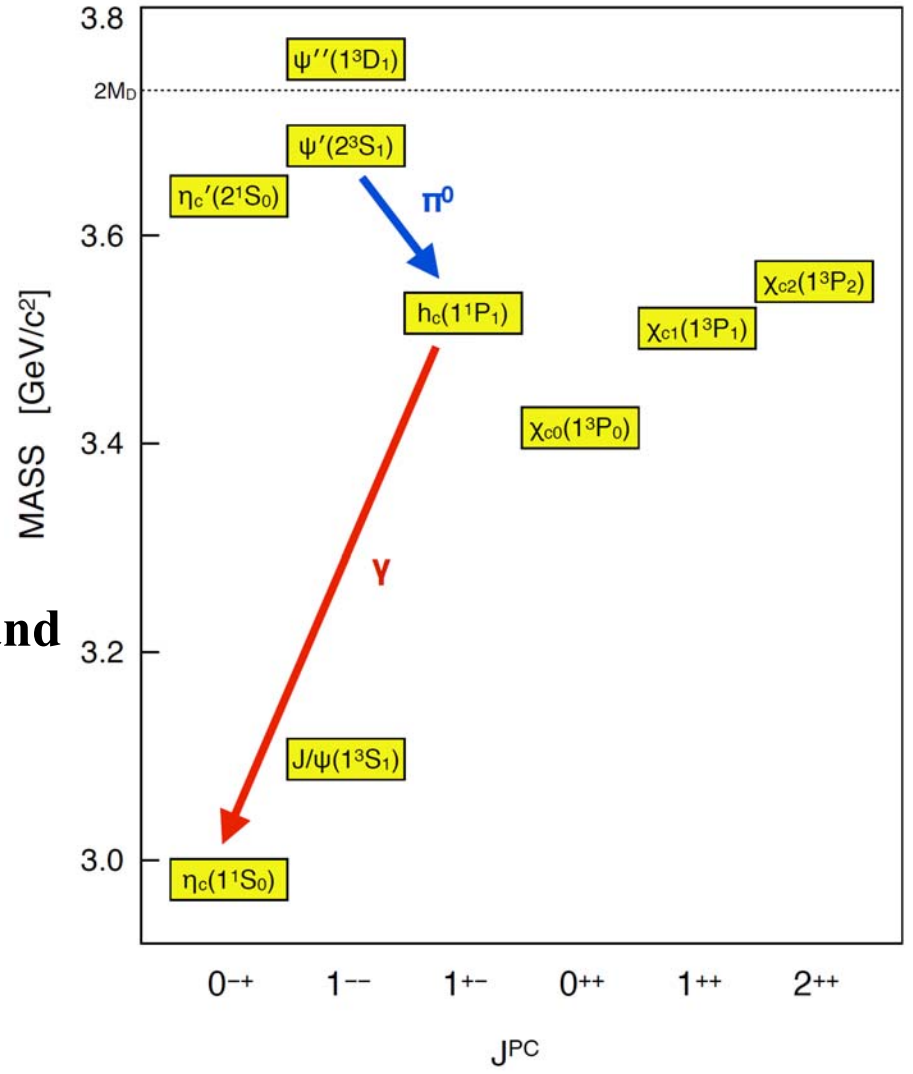


- Mar. 2008: Collisions at 500 mA ×500 mA, Lum.: 1 ×10^{32} $cm^{-2}s^{-1}$
- Apr. 30, 2008: Move BESIII to IP
- July 18, 2008: First e+e- collision event in BESIII
- Apr. 14, 2009 106 M ψ'events
- July 28, 2009 225 M J/ψ events
- June 27, 2010 0.975 fb^{-1} at ψ(3770) (includes 75 pb^{-1} scan)

$h_c(^1P_1)$

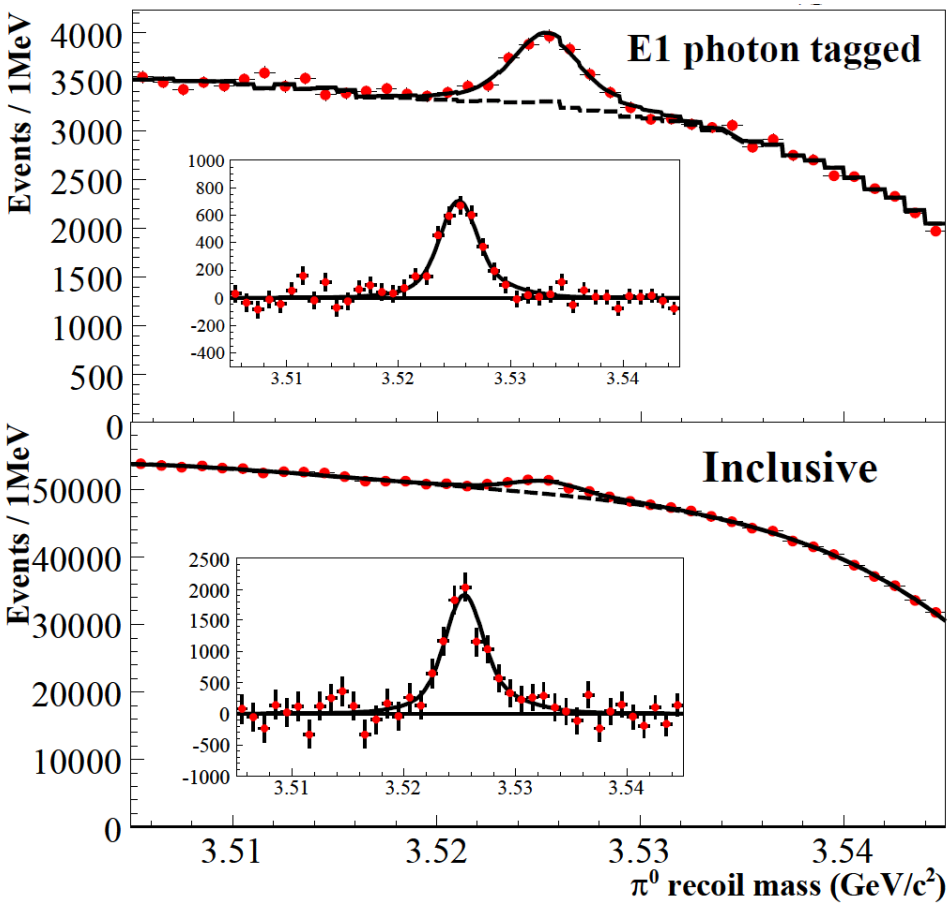
The least studied charmonium state below DD threshold

- $B(\psi' \to \pi^0 h_c)$ is a measure of isospin violation in hadronic charmonium decay
- Hyperfine ^1P mass splitting
  $\Delta M_{hf}(^1P) = \langle M(^3P_J)\rangle - M(^1P_1)$
  important to learn about spin-spin interaction of heavy quarks
  $\langle M(^3P_J)\rangle = 1/9(M\chi_{c0}+3M\chi_{c1}+5M\chi_{c1})$
- Large branching of E1 radiation transition
- Theory predictions for $B(h_c \to \gamma\eta_c)$ and $B(\psi' \to \pi^0 h_c)$ vary by factor ~2
- Only mass and combined brancing $Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma\eta_c)$ was measured before(CLEO, 2008)



h_c in $\psi' \to \pi^0 h_c$, $h_c \to \gamma \eta_c$ at BES III

Combined analysis of the inclusive and E1- tagged spectrums of recoil π^0



Select events with E1-photon to tag $h_c \to \gamma \eta_c$; Use tagged π^0 recoil mass spectrum to extract

- **$M(h_C)$**
- **$\Gamma(h_C)$ (first measurements)**
- **$B(\psi' \to \pi^0 h_c) \times B(h_c \to \gamma \eta_c)$**

Use inclusive π^0 recoil mass spectrum in combination with tagged results to obtain $B(\psi' \to \pi^0 h_c)$ and $B(h_c \to \gamma \eta_c)$ (first measurements)

h_c : results

- ✓ First measurements of $\Gamma(h_C)$, $Br(\psi' \to \pi^0 h_c)$ and $Br(hc \to \gamma \eta_c)$
- ✓ Hyperfine splitting $\Delta M_{hf}(^1P)$ is compatible with zero

	BES III PRL 104, 132002	CLEO-c PRL 101, 182003
$Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma \eta_C) * 10^{-4}$	4.58±0.40±0.50	4.16±0.30±0.37
M [MeV/c^2]	3525.40±0.13±0.18	3525.20±0.18±0.12
$\Delta M_{hf}(^1P)$ [MeV/c^2]	0.10±0.13±0.18	0.08±0.18±0.12

	BES III	Theoretical predictions
$\Gamma(h_C)$[MeV]	0.73±0.45±0.28 < 1.44 @ 90%CL	1.1 (NRQCD) Kuang 0.51 (PQCD) Kuang
$Br(h_c \to \gamma \eta_C)$[%]	54.3±6.7±5.2	41 (NRQCD) Kuang 88 (PQCD) Kuang 38 Godfrey, Rosner
$Br(\psi' \to \pi^0 h_c) \times 10^{-4}$	8.4±1.3±1.0	4 – 13 Kuang

Kuang, PRD65, 094024 (2002) Godfrey & Rosner, PRD 66, 014012 (2002)

$\psi' \to \gamma P$ ($P=\pi^0$, η and η')

- Important for testing various phenomenological mechanisms: VMD model, $\eta_c - \eta^{(\prime)}$ mixing, 2-gluon couplings to qq states, and final state radiation by light quarks.
- $R_{J/\psi} = B(J/\psi \to \gamma\eta)/ B(J/\psi \to \gamma\eta')$ predicted by 1st order perturbation theory.
- $R_{\psi'} = B(\psi' \to \gamma\eta)/ B(\psi' \to \gamma\eta') \approx R_{J/\psi}$ was expected.
- $B(\psi' \to \gamma \pi^0)$ expected to be small ($\sim 2.2 \times 10^{-7}$)

- Recently, CLEOc reported on J/ψ, ψ', $\psi'' \to \gamma P$:
  - Found no evidence for $\psi' \to \gamma\pi^0$ or $\gamma\eta$
  - Determine $B(\psi' \to \gamma\pi^0) < 5 \times 10^{-6}$
  - Obtain $R_{\psi'} < 1.8\%$ at 90% CL and $R_{J/\psi} = (21.1 +/- 0.9)\%$

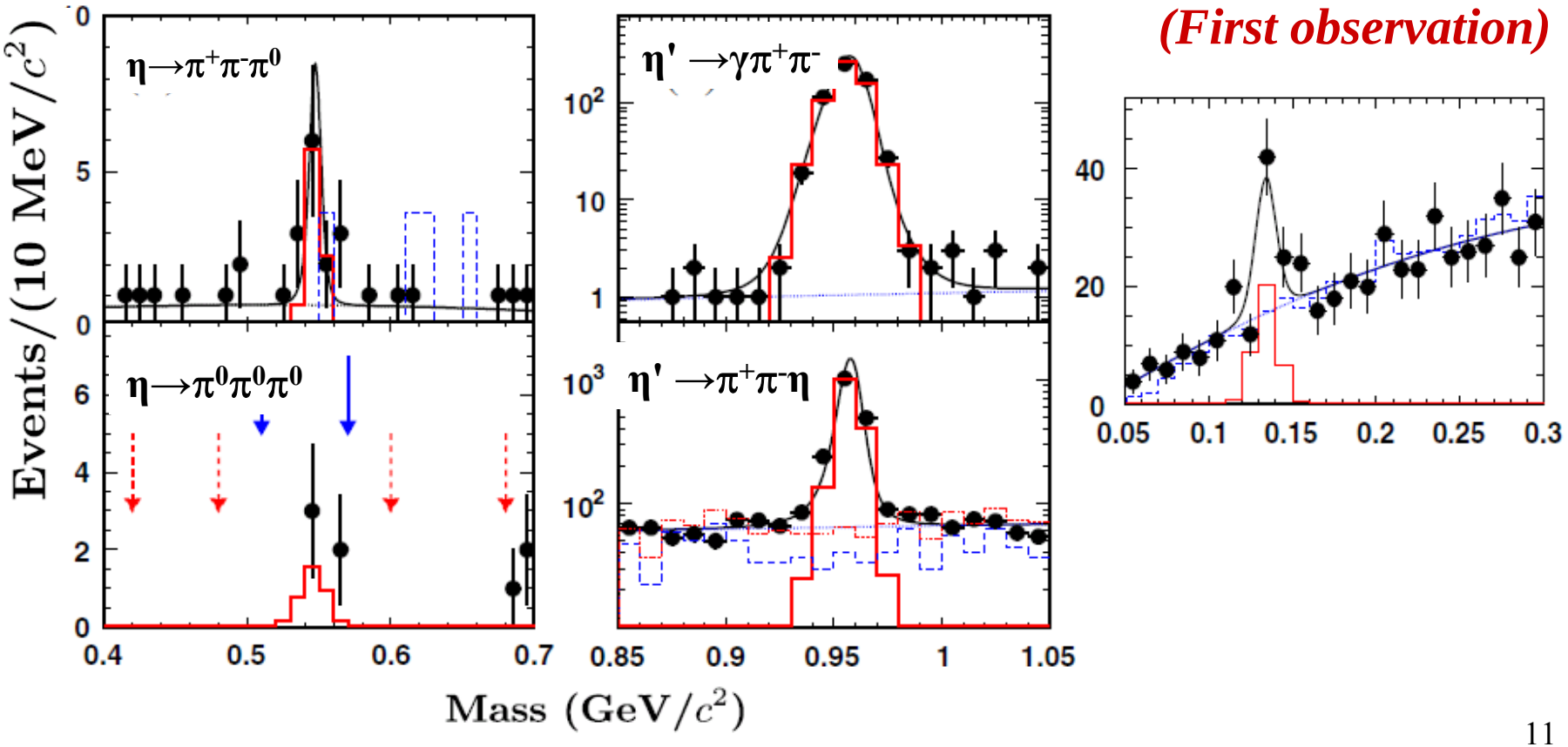
CLEOc, PRD 79, 111101 (2009)

$\psi' \to \gamma P$ (P=π^0, η and η') at BES III

$\psi' \to \gamma\eta$
$\eta \to \pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$
(First observation)

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

$\psi' \to \gamma\pi^0(\pi^0 \to \gamma\gamma)$
(First observation)



$\psi' \to \gamma P$ ($P=\pi^0$, η and η') at BES III

Phys. Rev. Lett 105, 261801 (2010)

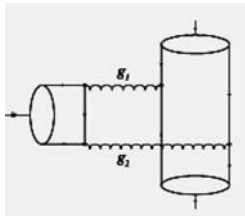
Mode	BESIII	Combined BESIII	PDG
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^-\pi^0)$	$1.78 \pm 0.72 \pm 0.17$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$		
$\psi' \to \gamma\eta'(\pi^+\pi^-\eta)$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

Branching Ratios (x 10^{-6})

- **Measured branching ratios of $\psi' \to \gamma\eta$ and $\psi' \to \gamma\pi^0$ for the first time**
- **The first measurement of $R_{\psi'} = (1.10 \pm 0.38 \pm 0.07)\%$**
- **Confirmed $R_{\psi'} << R_{J/\psi}$**

$R_{\psi'} << R_{J/\psi}$ poses a significant challenge to theory.

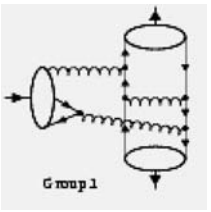
χ_{cJ} decays



Could be a good place to:

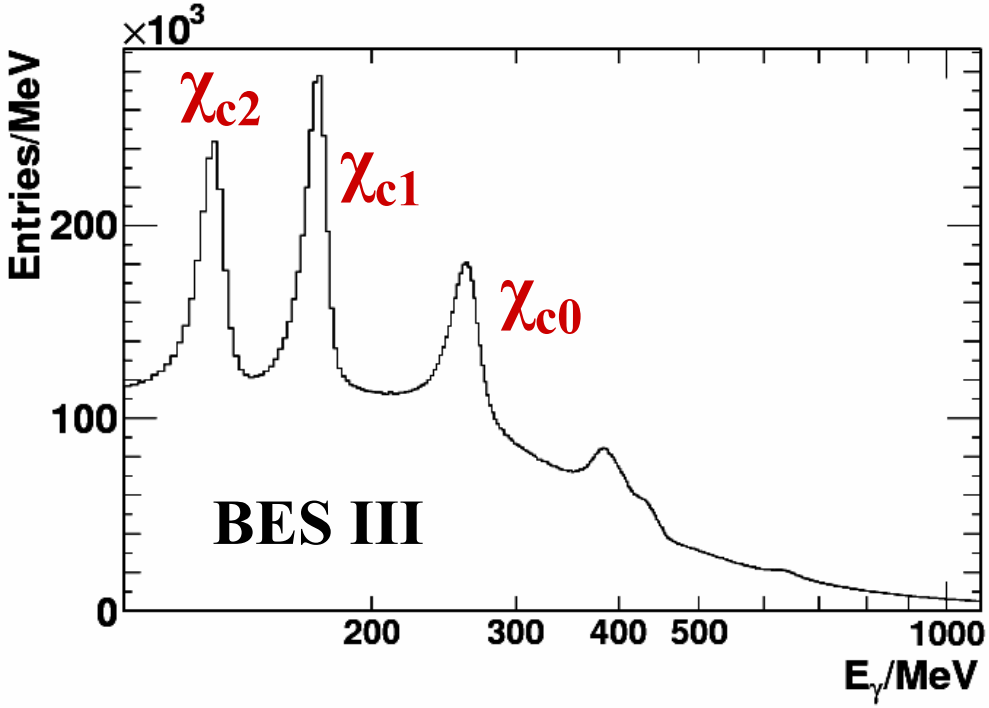
- **study gluonium: $\chi_c \rightarrow gg \rightarrow (qq)(qq)$.**

  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).



χ_{cJ} cannot directly originate from e^+e^- collisions, but can be easily produced and tagged in ψ' radiative decay

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

The recent experimental results (CLEOc: PRL 101, 151801 (2008)) for $B(\chi_{c1} \to \gamma\omega, \gamma\rho^0)$ are by an order of magnitude higher than the corresponding theoretical predictions.

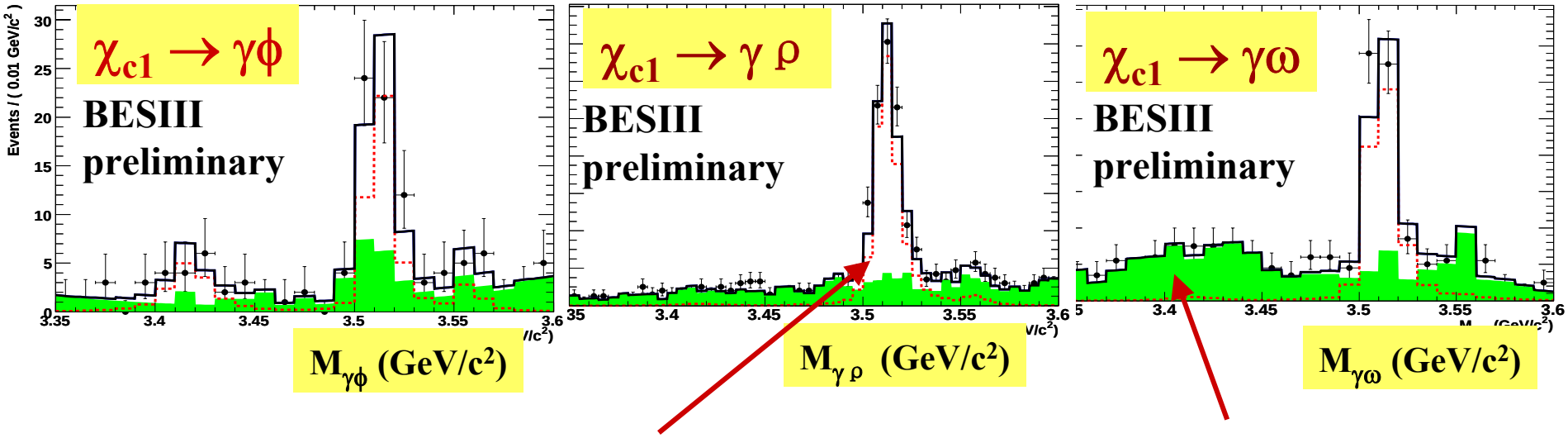
mode	CLEO	pQCD	NRQCD	NRQCD+QED
$B(\chi_{c1} \to \gamma\rho^0)*10^{-6}$	243 ± 19 ± 22	14	41	42
$B(\chi_{c1} \to \gamma\omega)*10^{-6}$	83 ± 15 ± 12	1.6	4.6	4.7

Difference may be explained by non-perturbative QCD "loop corrections" :
D. Y. Chen , Eur. Phys. J. C 70, 177 (2010)

New measurements are nesessary to check theory

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

- Select $\gamma\gamma K^+K^-$, $\gamma\gamma\pi^+\pi^-$, $\gamma\gamma\pi^+\pi^-\pi^0$ candidate for $\psi' \to \gamma\gamma\varphi$, $\psi' \to \gamma\gamma\rho$, $\psi' \to \gamma\gamma\omega$ event (mass windows for V, 4-C fit for total 4-momentum)
- Fit γV mass to extract χ_{cJ} event number



Signal (red) – obtained from MC

BG: Composition of V sidebands + 2-d order polynomial

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

BES III Prelimenary

First evidence of $\chi_{c1} \to \gamma\phi$

B (10^{-6})	BESIII	CLEOc	significance
$\chi_{c0} \to \gamma\phi$	< 16.1	< 6.4	2.9 σ
$\chi_{c1} \to \gamma\phi$	25.8 ± 5.2 ±2.0	< 26	6.4 σ
$\chi_{c2} \to \gamma\phi$	< 8.0	< 13	
$\chi_{c0} \to \gamma\rho^0$	< 10.2	< 9.6	
$\chi_{c1} \to \gamma\rho^0$	228 ± 13 ±16	243 ± 19 ± 22	>>10 σ
$\chi_{c2} \to \gamma\rho^0$	< 20.3	< 50	
$\chi_{c0} \to \gamma\omega$	< 12.7	< 8.8	
$\chi_{c1} \to \gamma\omega$	69.7 ± 7.2 ±5.6	83 ± 15 ± 12	>>10 σ
$\chi_{c2} \to \gamma\omega$	< 6.0	< 7.0	

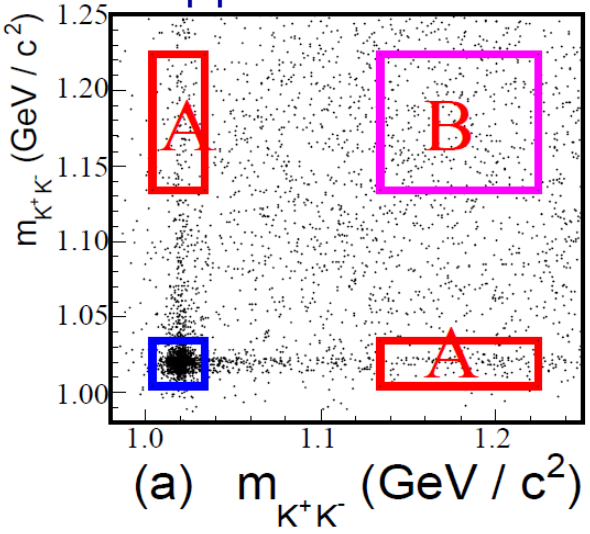
Study of $\chi_{cJ} \to VV$ (V = φ,ω) at BES III

- Only χ_{c0} and χ_{c2} decays into $\phi\phi$ and $\omega\omega$ have been observed.
- $\chi_{c1} \to$ VV is suppressed due to helicity selection rule in pQCD
- $\chi_{cJ} \to \omega\ \phi$ is doubly OZI suppressed, never observed before

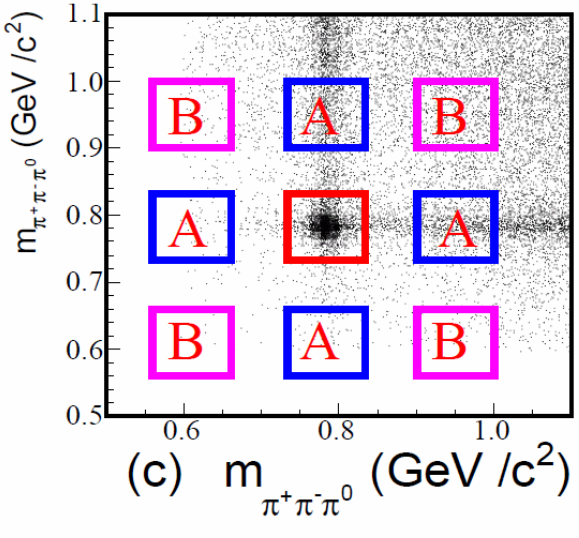
Study of $\chi_{cJ} \to VV$ (V = φ,ω) at BES III

Signal and sideband areas for φφ→4K, ωω→2($\pi^+\pi^-\pi^0$), φω→KK$\pi^+\pi^-\pi^0$ and φφ→KK$\pi^+\pi^-\pi^0$ candidates

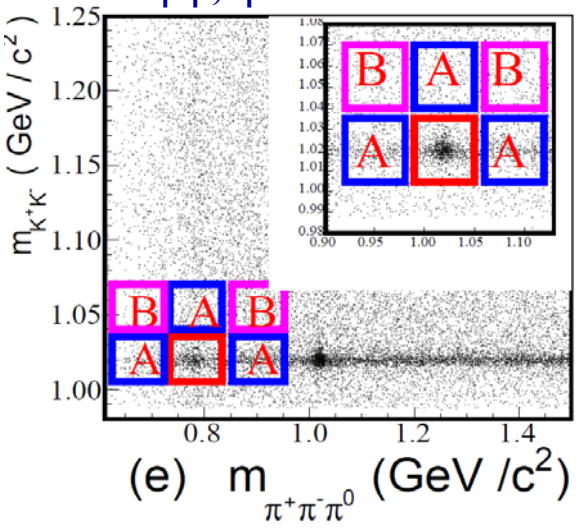
φφ→4K



ωω→2(πππ)

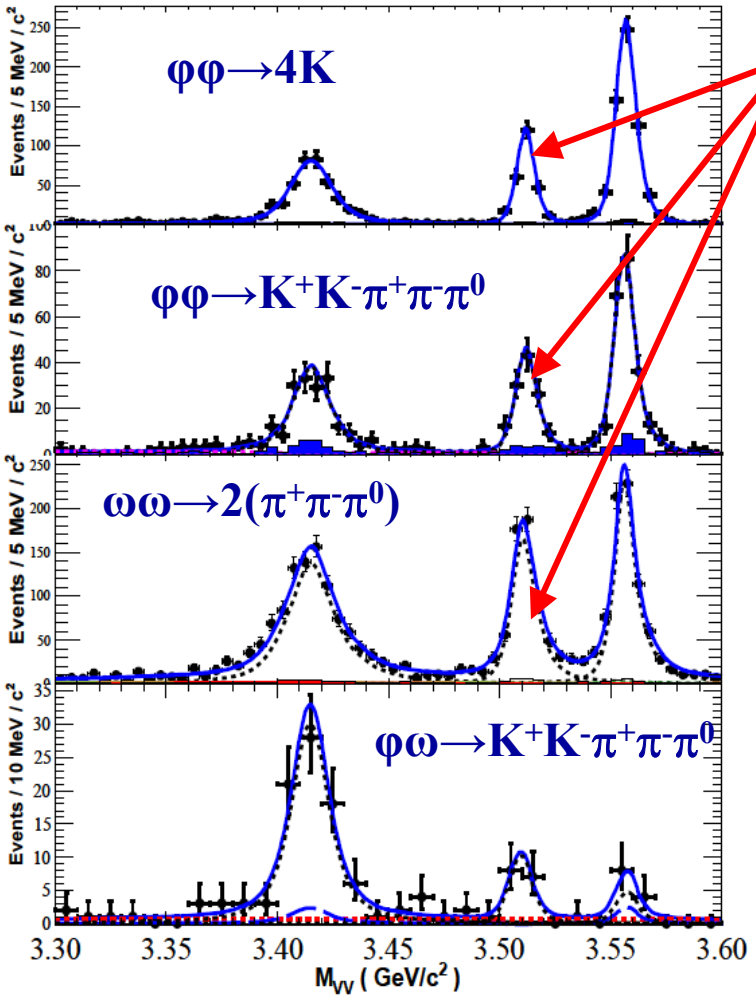


φφ, φω→KKπππ



PID and total 4-momentum 4C-kinematic fit constraint applied to all γVV candidate : χ2(4C)<60 for γφφ and γωφ candidate, χ2(4C)<200 for γωω

Study of $\chi_{cJ} \to VV$ (V = φ,ω) at BESIII



surprisingly clear χ_{c1} signal

Fit M(VV) spectrum with signal and backgrounds combination to extract branchings

Signal: MC χ_{CJ} shape (gray dotted line)

Backgrounds:

- Normalized sidebands (filled blue)
- Phase-space for non - χ_{CJ}
- 2-nd order polynomial for combinatorial bg (red line)

Results of $\chi_{cJ} \to VV$ (V = φ,ω) at BESIII

BES III Preliminary

Final states	Channel	$N_{\rm net}$	ϵ (%)	$Br(\times 10^{-4})$	PDG [13]
$\gamma 2(K^+K^-)$	$\chi_{c0} \to \phi\phi$	432.1 ± 22.6	22.41	$7.81 \pm 0.38 \pm 0.80$	9.3 ± 2.0
	$\chi_{c1} \to \phi\phi$	253.6 ± 16.5	26.43	$4.06 \pm 0.26 \pm 0.43$	$- - -$
	$\chi_{c2} \to \phi\phi$	629.3 ± 25.7	26.11	$10.74 \pm 0.43 \pm 1.10$	15.4 ± 3.0
$\gamma K^+K^-\pi^+\pi^-\pi^0$	$\chi_{c0} \to \phi\phi$	178.8 ± 16.2	1.92	$9.13 \pm 0.83 \pm 1.04$	9.3 ± 2.0
	$\chi_{c1} \to \phi\phi$	111.6 ± 12.0	2.31	$4.95 \pm 0.53 \pm 0.59$	$- - -$
	$\chi_{c2} \to \phi\phi$	217.9 ± 16.1	2.23	$10.55 \pm 0.78 \pm 1.22$	15.4 ± 3.0
Combined	$\chi_{c0} \to \phi\phi$	—	—	$8.00 \pm 0.35 \pm 0.80$	9.3 ± 2.0
	$\chi_{c1} \to \phi\phi$	—	—	$4.30 \pm 0.23 \pm 0.49$	$- - -$
	$\chi_{c2} \to \phi\phi$	—	—	$10.67 \pm 0.38 \pm 1.15$	15.4 ± 3.0
$\gamma 2(\pi^+\pi^-\pi^0)$	$\chi_{c0} \to \omega\omega$	991.1 ± 38.2	13.13	$9.53 \pm 0.37 \pm 1.11$	23 ± 7.0
	$\chi_{c1} \to \omega\omega$	597.1 ± 28.8	13.23	$5.96 \pm 0.28 \pm 0.70$	$- - -$
	$\chi_{c2} \to \omega\omega$	762.4 ± 31.3	11.91	$8.90 \pm 0.36 \pm 1.08$	20.0 ± 7.0
$\gamma K^+K^-\pi^+\pi^-\pi^0$	$\chi_{c0} \to \omega\phi$	76.0 ± 11.0	14.7	$1.18 \pm 0.17 \pm 0.15$	—
	$\chi_{c1} \to \omega\phi$	15.3 ± 4.1	16.2	$0.23 \pm 0.06 \pm 0.03$	—
	$\chi_{c2} \to \omega\phi$	< 12.5	15.7	< 0.23	—

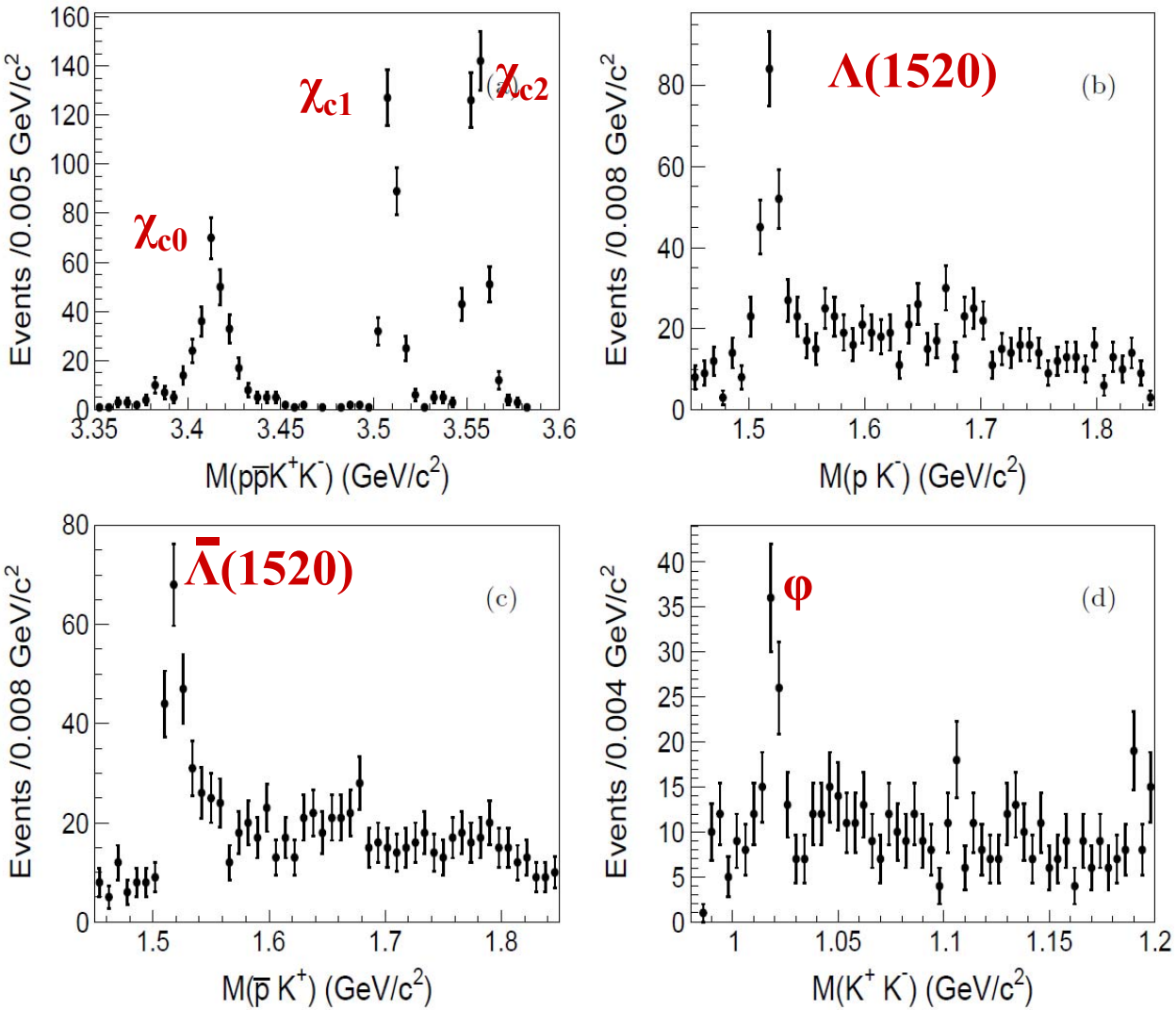
- $\chi_{C1} \to \varphi\varphi$, $\omega\omega$ decays are observed for the first time with surprisingly large branching. Is helicity selection rules applicable in this case?
- The doubly OZI-suppressed decay $\chi_{CJ} \to \varphi\omega$ is observed for the first time
- Other measured branchings are consistent with and more accurate then previous measurements

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

- **Color Octer Mechanism disagrees with the measurements for some baryon-antibaryon χ_{cJ} decays (e.g. $\chi_{cJ} \to \Lambda\bar{\Lambda}$)**
- **Only ground state baryons was observed in χ_{cJ} decays**
- **To test the COM predictions for P-wave charmonia decay further, measurements of χ_{cJ} excited baryon pair decays are needed**
- **The main aim of analysis is to find contribution of intermediate $\Lambda(1520)$ in $K^+K^-p\bar{p}$ final state**

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

Clear sign of Λ(1520) and φ



γK^+K^-pp candidate selected using PID info and 4C kinematic fit

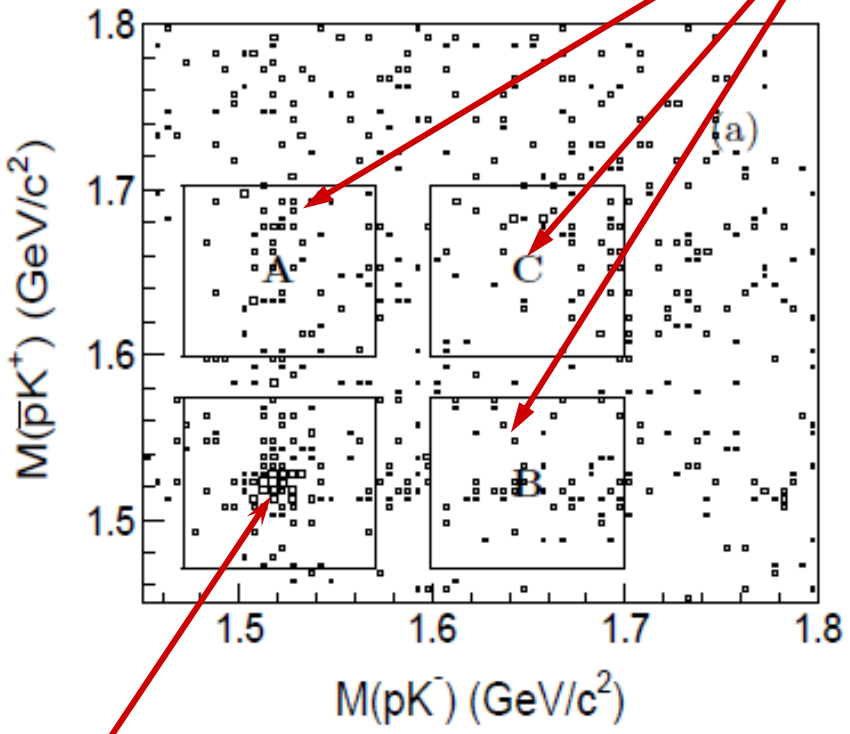
Study of $\chi_{cJ} \to K^+K^-p\bar{p}$ at BES III

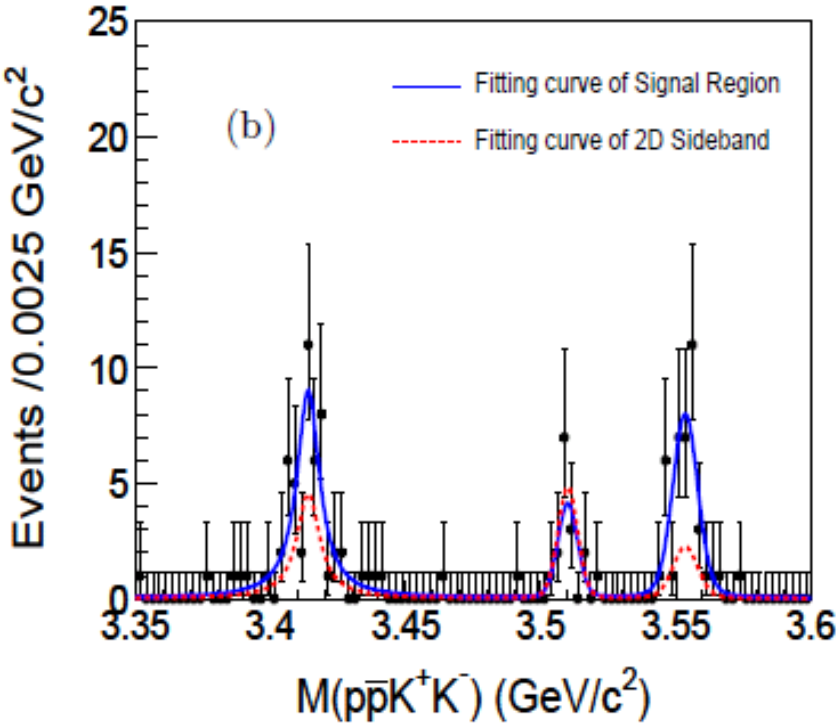
Search for $\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520)$

Reject φ by veto cut

sideband area used to find BG shape

Fit M(KKpp) to extract Br





signal area

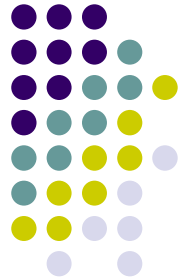
Results of $\chi_{cJ} \to K^+K^-p\bar{p}$ at BESIII

BES III Preliminary

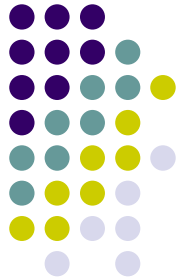
	χ_{c0}	χ_{c1}	χ_{c2}
$Br(\chi_{cJ} \to p\bar{p}K^+K^-) \times 10^{-4}$	$1.24 \pm 0.20 \pm 0.18$	$1.35 \pm 0.15 \pm 0.19$	$2.08 \pm 0.19 \pm 0.30$
$Br(\chi_{cJ} \to \bar{p}K^+\Lambda(1520) + c.c.) \times 10^{-4}$	$3.00 \pm 0.58 \pm 0.50$	$1.81 \pm 0.38 \pm 0.28$	$3.06 \pm 0.50 \pm 0.54$
$Br(\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520)) \times 10^{-4}$	$3.18 \pm 1.11 \pm 0.53$	$< 1.00@90\% C.L.$	$5.05 \pm 1.29 \pm 0.93$
$Br(\chi_{cJ} \to p\bar{p}\phi) \times 10^{-5}$	$6.12 \pm 1.18 \pm 0.86$	$< 1.82@90\% C.L.$	$3.04 \pm 0.85 \pm 0.43$

Main sources of systematic: tracking efficiency (~8%), PID(~8%), fiting procedure (0-9%), branchings (3-7%), mass windows cut (2-11%)

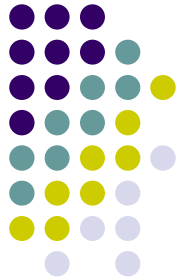
Summary



- **The BES-3 experiment runs successfully, and already provided many interesting results**
- **Many the world best measurements in charmonium physics during last year, and a number of measurements were made for the first time**
- **Some of our results are quite unexpected**
- **Now it is turn of theorists to explain our findings**
- **Much more new exciting results from BES-3 are coming soon**



Thank you



BACKUP SLIDES

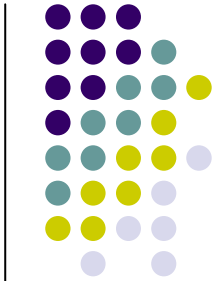
First publications of BESIII

- **Charmonium Spectroscopy and Transitions**
  - **Measurements of h_c in ψ' decays *(PRL 104, 132002 (2010))***
- **Charmonium Decays**
  - **$\chi_{cJ} \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))***
  - **$\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(arXiv:1011.0885, PRL. 105, 261801 (2010))***
  - **$\chi_{cJ} \to 4\pi^0$ *(arXiv:1011.6556, PRD 83, 012006 (2011))***
- **Light Quark States**
  - **$a_0(980) - f_0(980)$ mixing *(PRD 83, 032003 (2011))***
  - **$\eta' \to \eta\pi^+\pi^-$ matrix element *(arXiv:1012.1117, PRD 83, 012003 (2011))***
  - **X(1860) in $J/\psi \to \gamma$(pp) *(Chinese Physics C 34, 4 (2010))***
  - **X(1835) in $J/\psi \to \gamma(\eta'\pi^+\pi^-)$ *(PRL 106, 072002 (2011).)***

BESIII Collaboration

More then 300 physicist
48 institutions from 9 contries

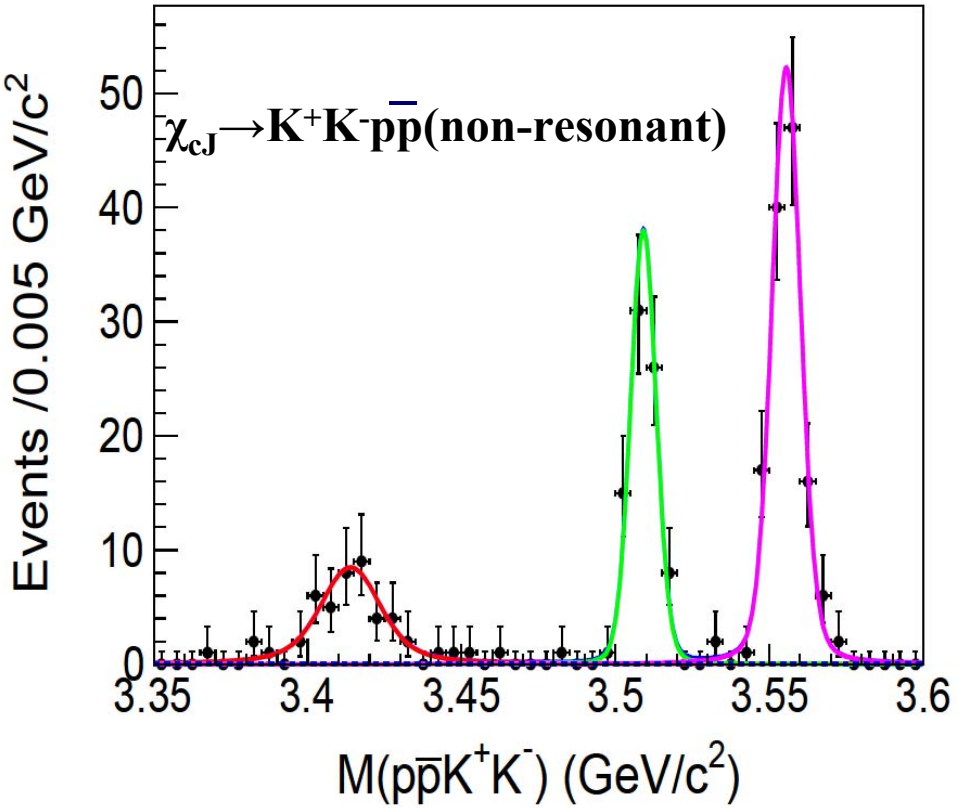
$\chi_{cJ} \to K^+K^-pp$ at BESIII
non-resonant contribution



4-body $\chi_{cJ} \to KKpp$

selected applying veto cuts on KK and Kp mass:

- $|M(pK^-)-1.52| > 0.07$ GeV/c2,
- $|M(K^+p)-1.52| > 0.07$ GeV/c2
- $|M(K^+K^-) - 1.02| > 0.03$ GeV/c



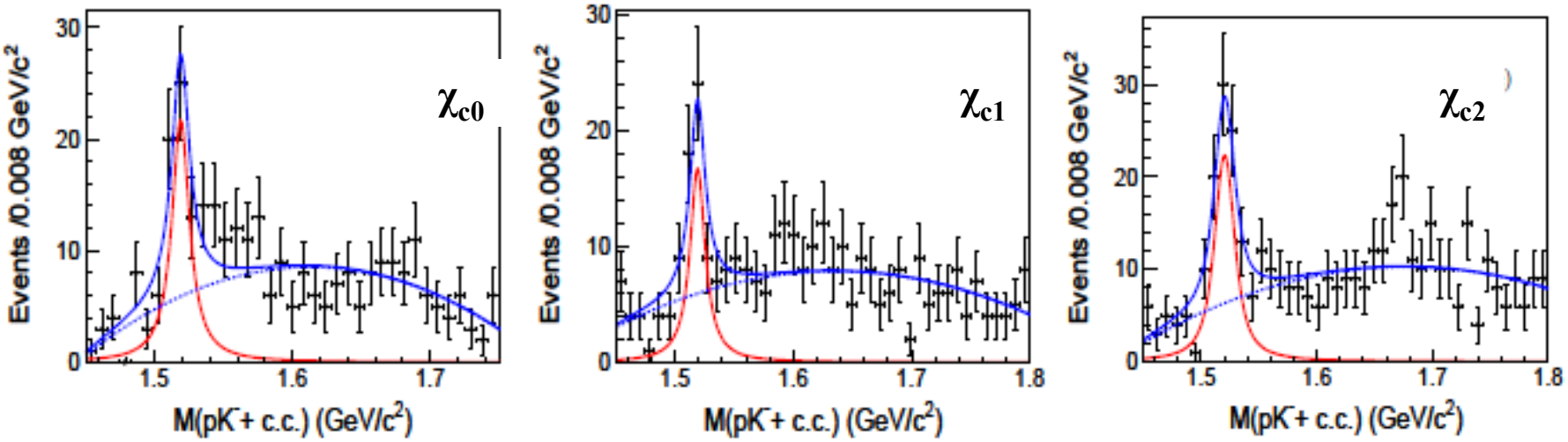
$\chi_{cJ} \to K^+K^-p\bar{p}$ at BESIII

$\chi_{cJ} \to pK^+\bar{\Lambda}(1520)$ + c.c.

Separate analysys for χc0 χc1, χc2 candidates

χ_{c0} : 3.365 GeV/c2 < M($p\bar{p}K^+K^-$) < 3.455 GeV/c2
χ_{c1} : 3.490 GeV/c2 < M($p\bar{p}K^+K^-$) < 3.530 GeV/c2
χ_{c2} : 3.530 GeV/c2 < M($p\bar{p}K^+K^-$) < 3.580 GeV/c2
+ $\bar{\Lambda}$ veto, + φ veto

Fit: BW x gauss, BG:2d-order polynomial



Similar procedure for $\chi_{cJ} \to p\bar{p}\varphi$