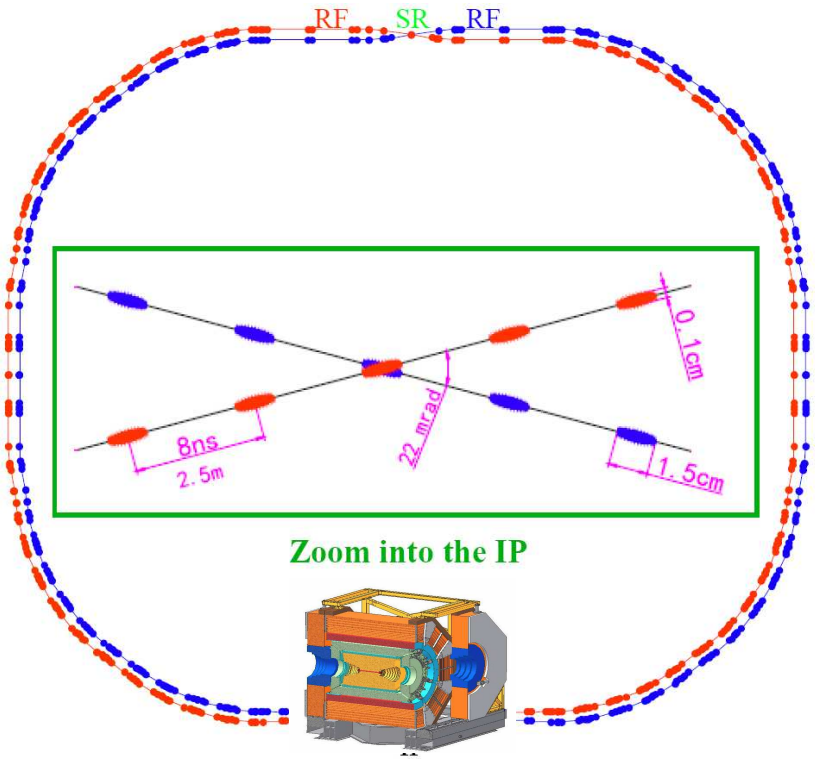
Эксперимент BES-III: новые результаты в физике чармония и его распадов

Научная сессия-конференция секции ЯФ ОФН РАН

Физика фундаментальных взаимодействий

Дедович Дмитрий (ОИЯИ)
коллаборация BESIII

BEPCII storage rings



Beam energy: 1.0 - 2.3 GeV

Peak Luminosity:

Design: **1×10^{33} $cm^{-2}s^{-1}$**

Achieved: **0.65×10^{33} $cm^{-2}s^{-1}$**

Optimum energy: 1.89 GeV

Energy spread: 5.16×10^{-4}

Circumference: 237 m

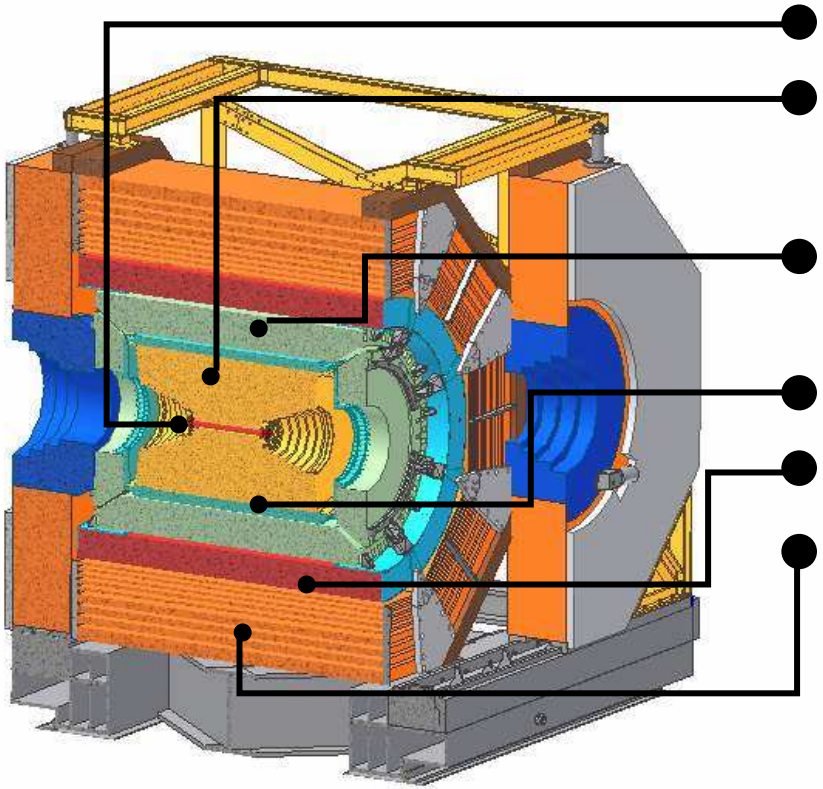
Beam energy measurement: Using Compton backscattering technique. Accuracy up to **5×10^{-5}**

Physics of τ-charm region

- **Charmonium physics**
  - **charmonium state & transitions**
  - **charmonium decays**
- **Light hadron physics in J/ψ decay**
  - **Meson & barion spectroscopy**
  - **Search for exotic**
- **Open charm**
  - **absolute branchings**
  - **decay constants f_D&f_{DS} ,CKM, LQCD calibration for B-physics**
  - **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:**
  $\delta p/p$=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**

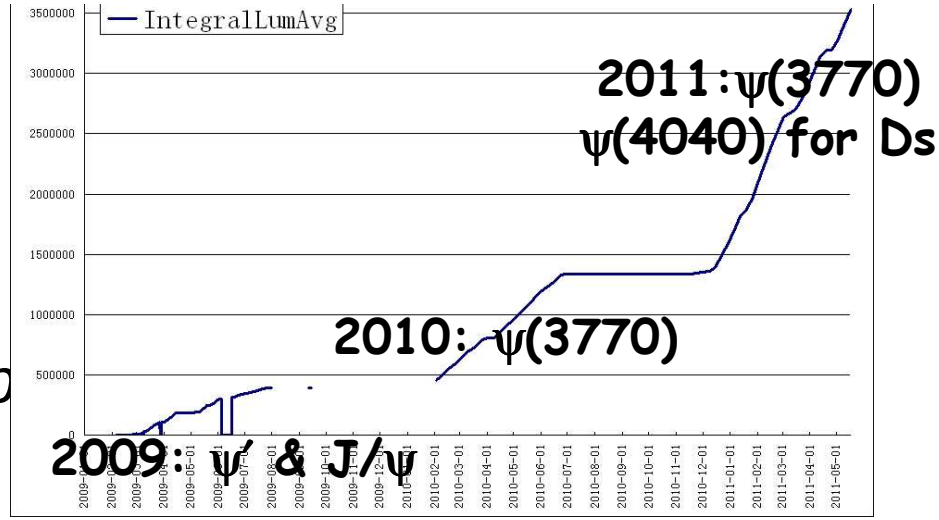
Close to 4π acceptance(93%), very little material inside tracker, excellent tracking & calorimetry

Data Samples

- *BESIII collected*
  - 2009: **225 M** J/ψ
  - 2009: **106 M** ψ'
  - 2010-11: **2.9 fb^{-1}** ψ(3770)
    (3.5 × CLEOc 0.818 fb^{-1})
  - 2011-05:**477 pb^{-1}** @4010MeV
    (for D_S and XYZ spectroscop

Int. luminosity: 2009.01– 2011.06

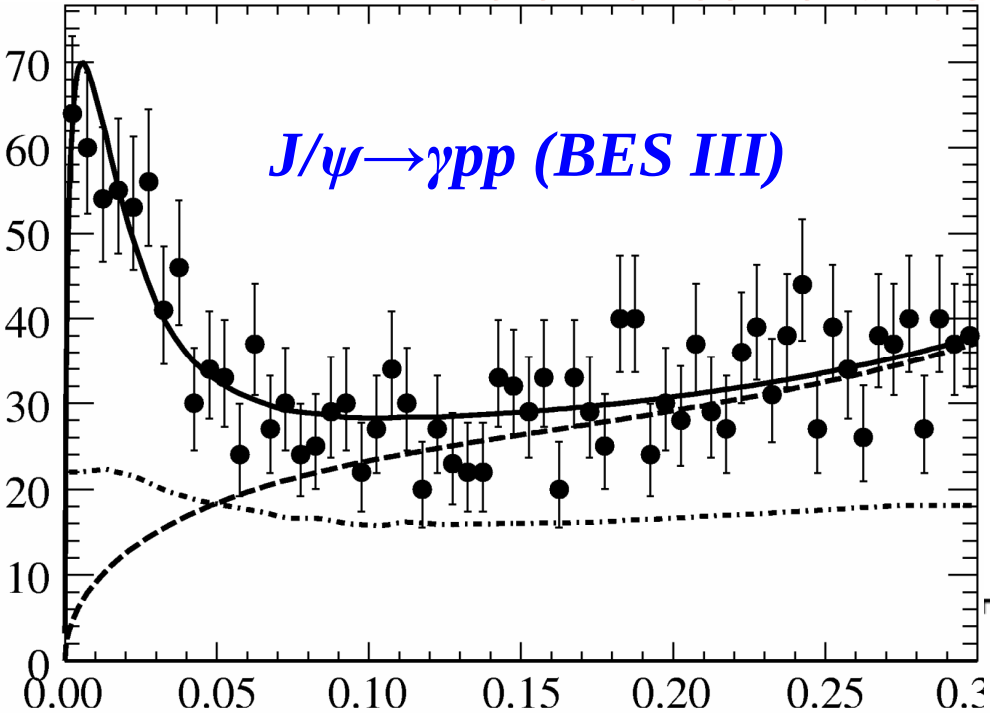
~ 4.0 fb^{-1} @ all energies

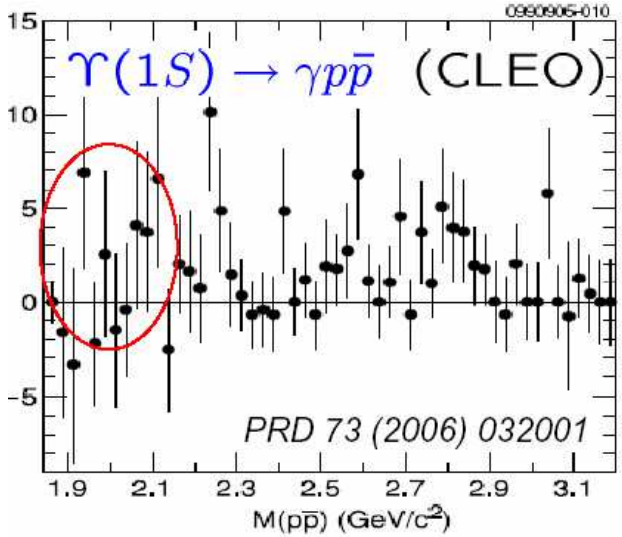


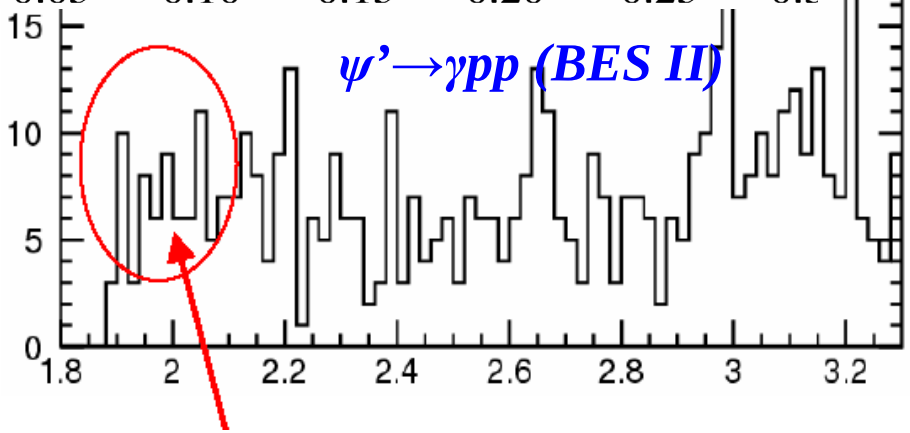
- *BESIII data-taking plans*
  - 2012: 1 billon J/ψ, 0.7~1 billon ψ'
  - 2013: @4170 MeV D_S physics; R scan
  - 2014: ψ'/T/ R scan
  - ψ(3770) 5-10 fb^{-1}

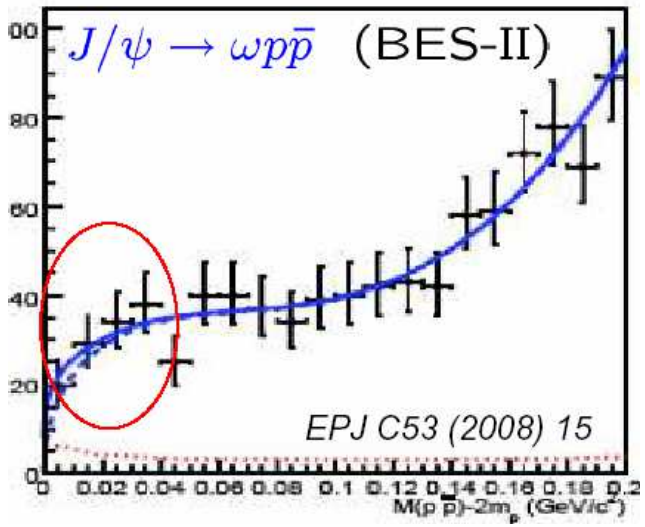
$p\bar{p}$ threshold enhancement in $J/\psi \to \gamma p\bar{p}$

No enhancement was found in similar decays

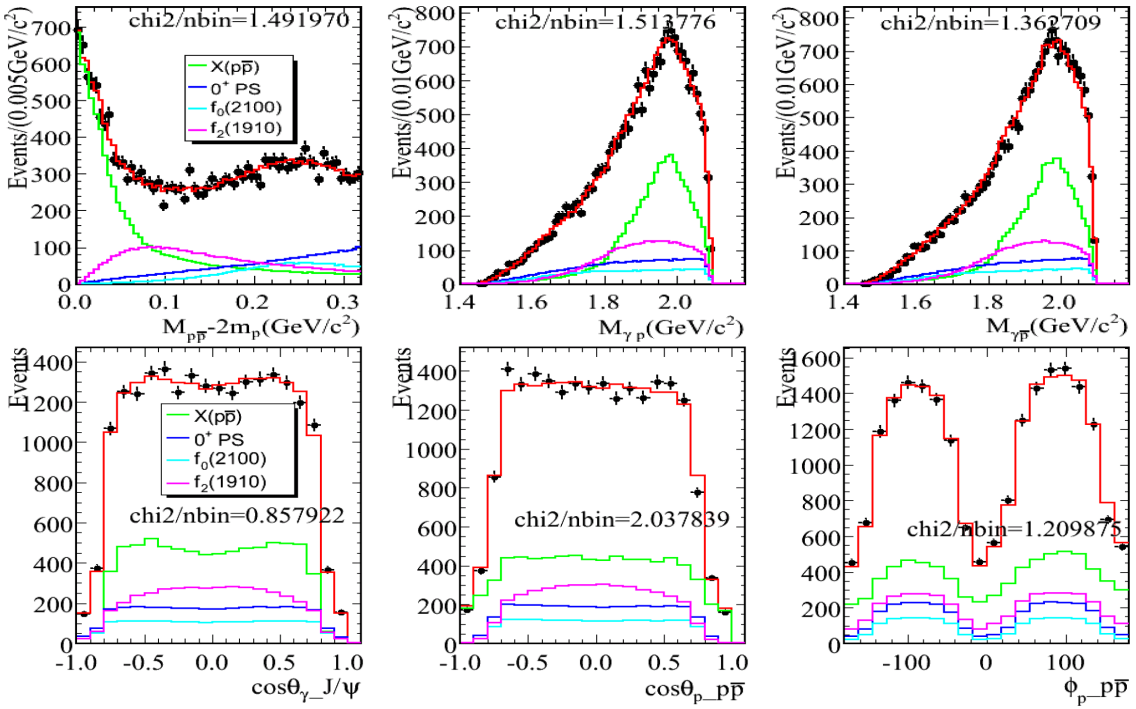








PWA near $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$



- $f_0(2100)$ / $f_2(1910)$ fixed to PDG.
- Including FSI result in substantial improvement of the fit; diferent FSI models used to estimate systematic

$$J^{PC} = 0^{-+}$$

Prelimenary PWA results for X(pp):

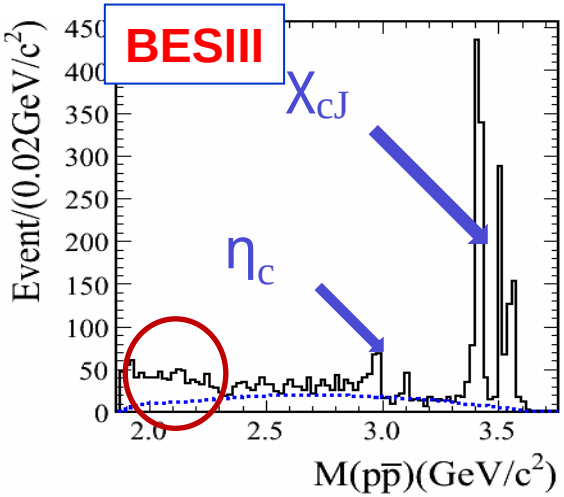
$$M = 1832^{+19}_{-5}\ (stat)^{+19}_{-17}\ (syst) \pm 19\ (FSI\ model)\ MeV/c^2$$

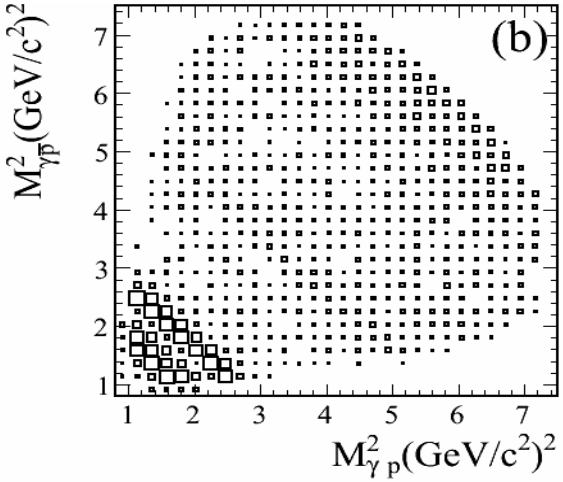
$$\Gamma = 13 \pm 39\ (stat)^{+11}_{-33}\ (syst) \pm 4\ (FSI\ model)\ MeV/c^2$$

$$Br = (9.0^{+0.4}_{-1.1}\ (stat)^{1.5}_{5.1}\ (syst) \pm 2.3(FSImodel)) \times 10^{-5}$$

PWA on the $p\bar{p}$ mass threshold structure in $\psi' \to \gamma p\bar{p}$

Obviously different line shape of $p\bar{p}$ mass spectrum near threshold from that in J/ψ decays





Preliminary PWA results:

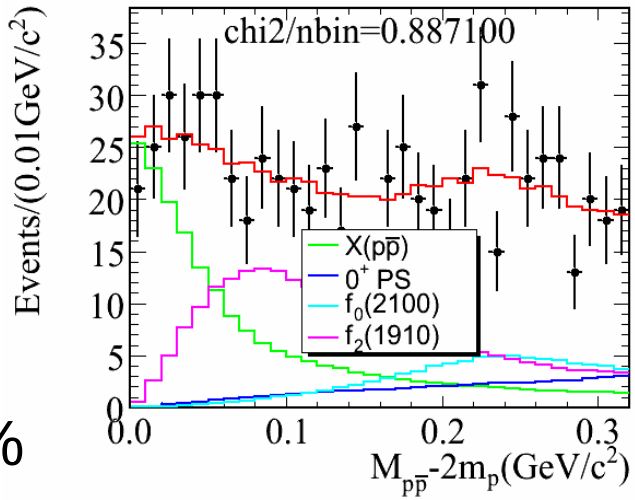
- The production ratio R:

$$R = \frac{B(\psi' \to \gamma X(p\bar{p}))}{B(J/\psi \to \gamma X(p\bar{p}))}$$

$$= (5.08 \pm 0.56(\text{stat})^{+0.72}_{-3.83}(\text{syst}) \pm 0.12(\text{mod}))\%$$

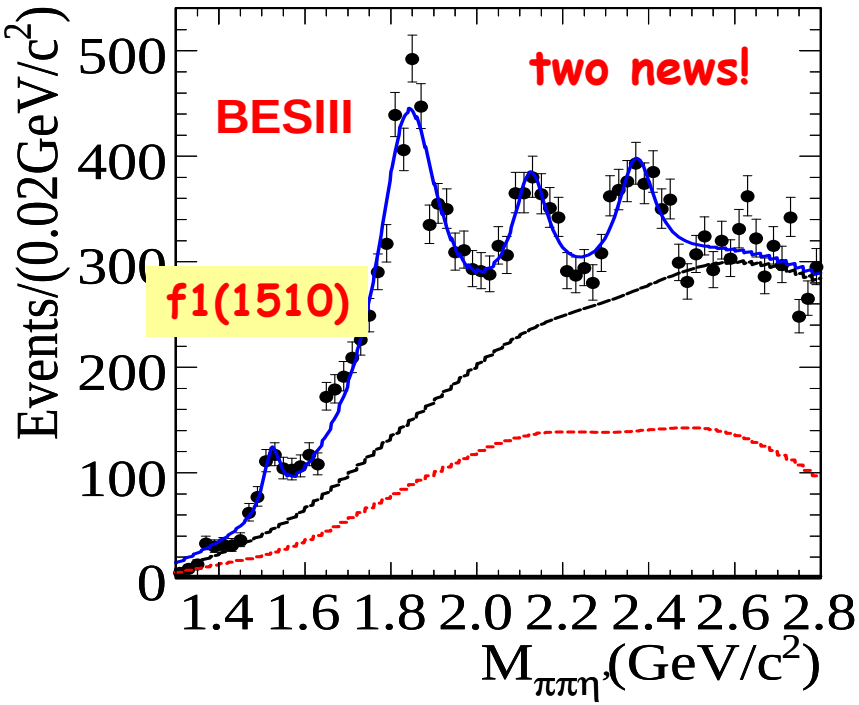
- It is suppressed compared with “12% rule”.

PWA Projection:



X(1835) and new structures in $J/\psi \to \gamma\eta'\pi^+\pi^-$

PRL 106, 072002(2011)

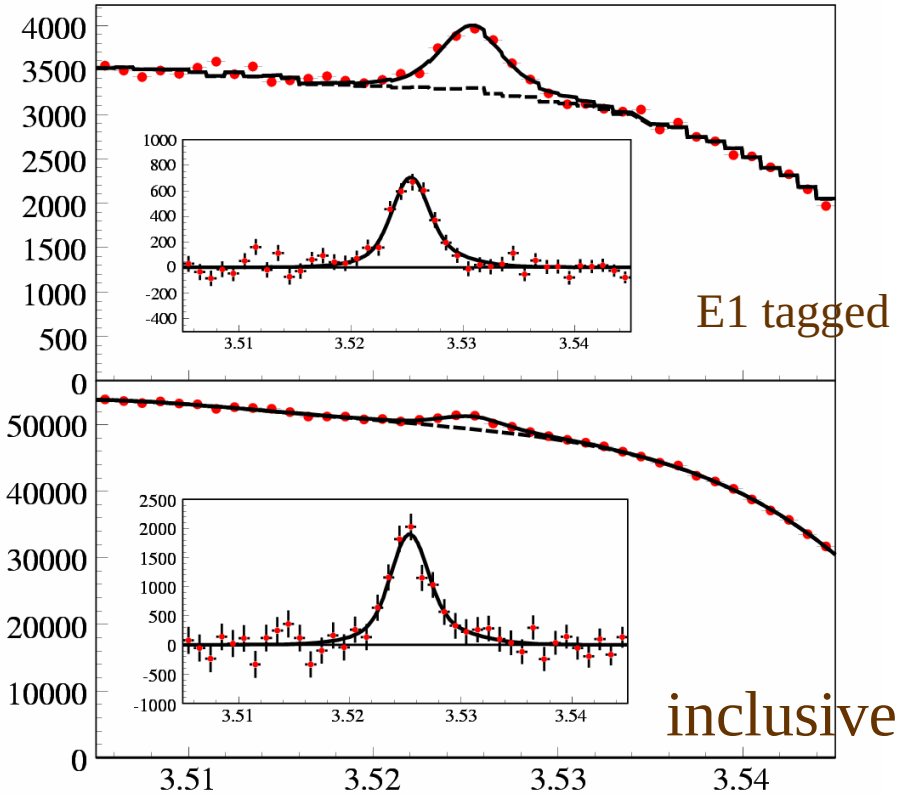


X(1835) consistent with 0^{-+}, but the others are not ruled out.

Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ

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

The least studied charmonium bellow open charm



BESIII: PRL 104 132002 (2010)

Mass = **3525.40±0.13±0.18** MeV/c^2

Width = **0.73±0.45±0.28** MeV

<1.44 MeV @90%

First measurement

CLEOc: PRL 101 182003 (2008)

Mass = **3525.28±0.19±0.12** MeV

Width: fixed at 0.9 MeV

$\Delta M_{hf}(1P) = M(h_c) - \langle m(1\,^3P_J)\rangle$

BESIII: ***0.10±0.13±0.18*** MeV/c^2

CLEOc: ***0.02±0.19±0.13*** **MeV/c^2**

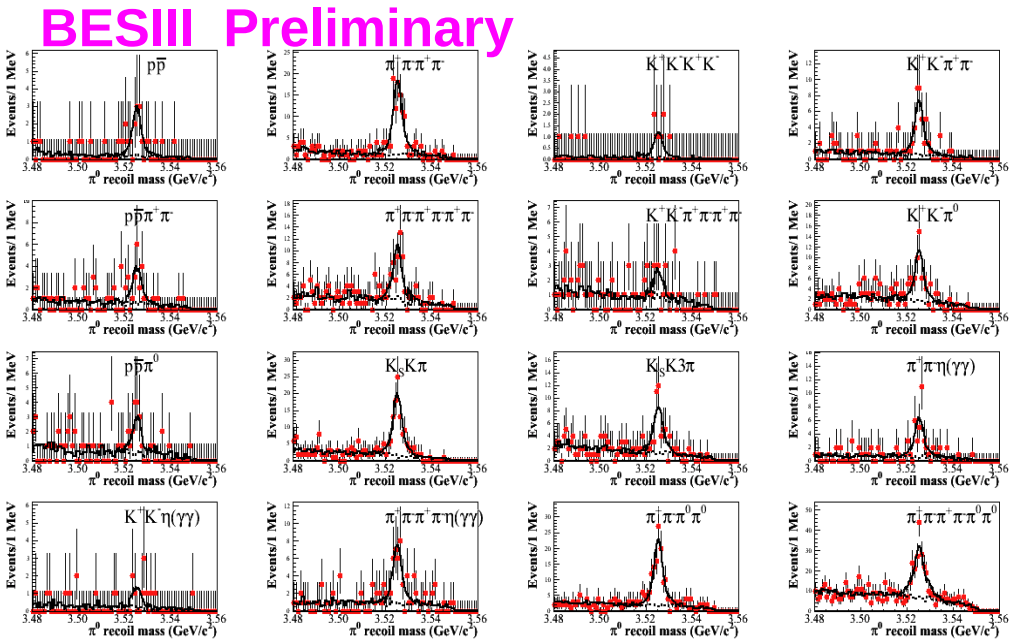
By combining inclusive results with E1-photon tagged results

$BF(\psi' \to \pi^0 h_c)$ = **(8.4±1.3±1.0) ×10^{-4}**

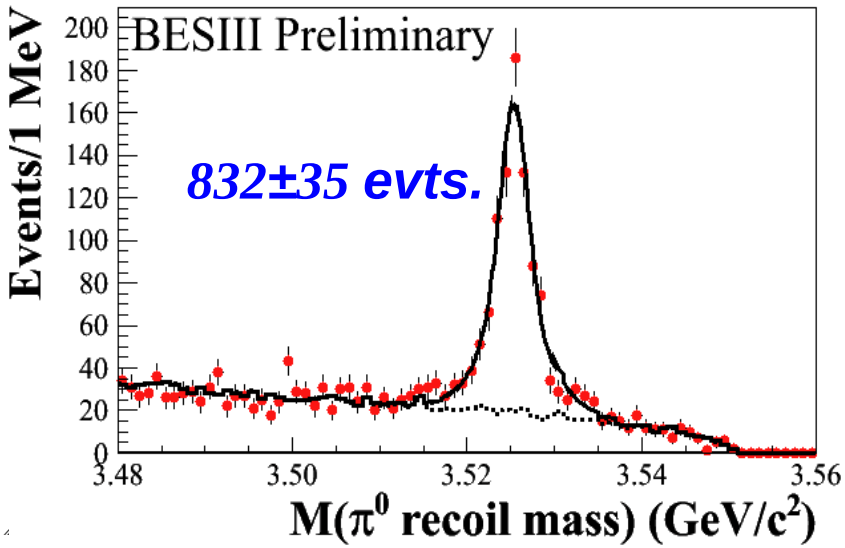
$BF(h_c \to \gamma \eta_c)$ = **(54.3±6.7±5.2)%**

First measurement

$\psi' \to \pi^0 h_c$, $h_c \to \gamma \eta_c$, η_c exclusive decays



Summed distribution



Simultaneous fit to π^0 recoiling mass

χ^2/d.o.f. = 32/46

Mass = **3525.31±0.11±0.15** MeV/c^2

Width = **0.70±0.28±0.25** MeV

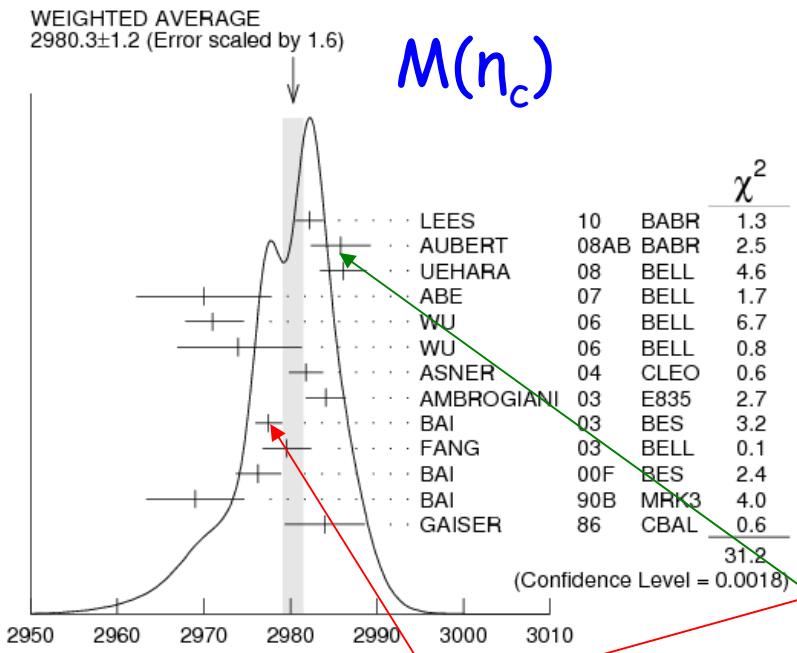
Consistent with BESIII inclusive and CLEOc results

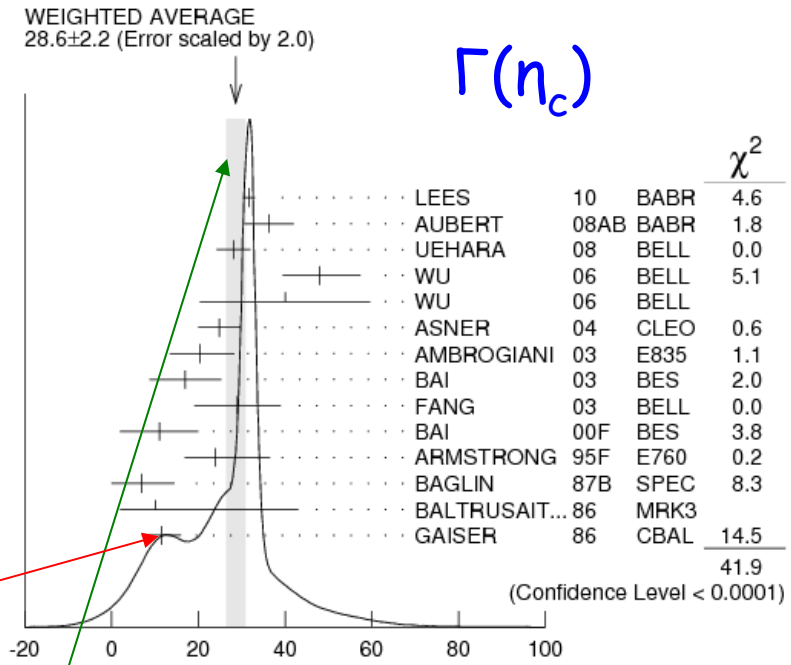
Currently the most precise measurements

η_c

- Known for 30 years, but still its mass and width are known by an order of magnitude worse than of J/ψ, ψ', χ_{cJ}

PDG'11





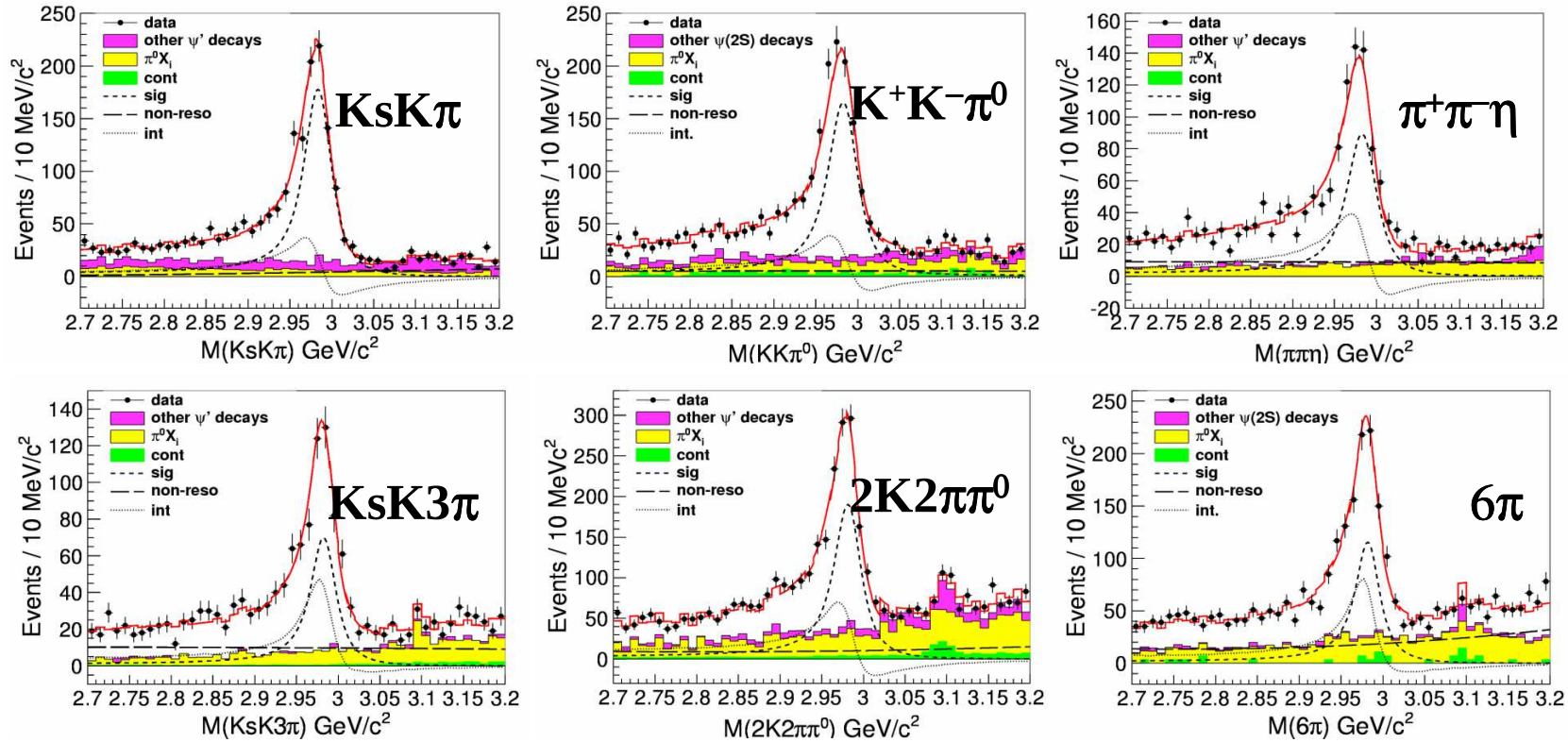
J/ψ radiative transition:
$M(\eta_c) \sim 2978.0$ MeV
$\Gamma(\eta_c) \sim 10$ MeV

Two-photon production:
$M(\eta_c) = 2983.1 \pm 1.0$ MeV,
$\Gamma(\eta_c) = 31.3 \pm 1.9$ MeV.

CLEO-c recently reported the distortion of η_c lineshape in ψ' decays

$\psi' \rightarrow \gamma\eta_c$, η_c exclusive decays

BESIII Preliminary



Relative phase ϕ values from each mode are consistent within 3σ,

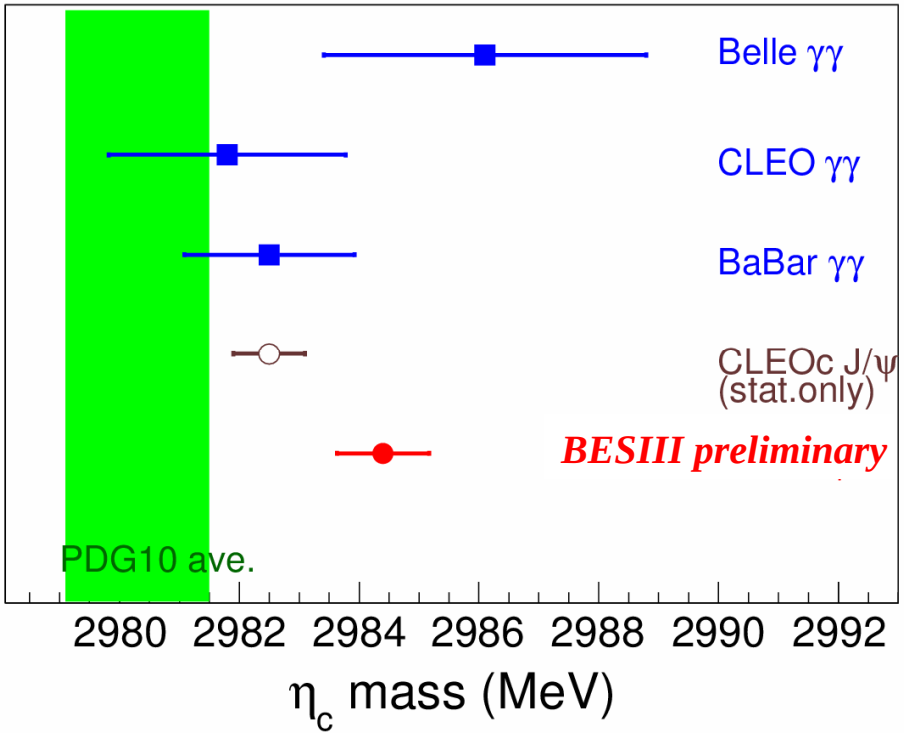
➔ use a common phase value in the simultaneous fit.

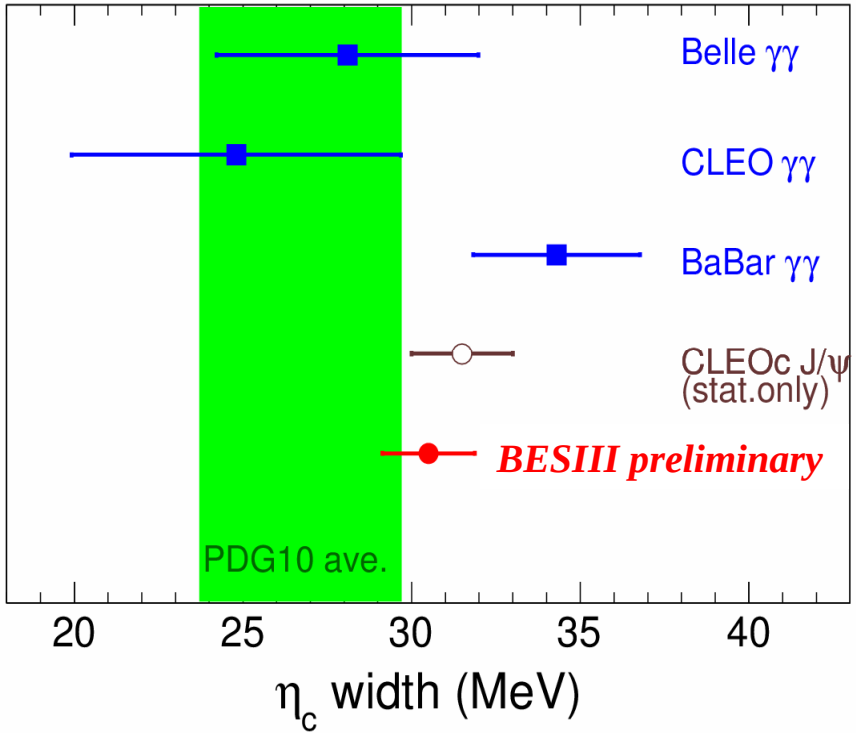
M: **2984.4±0.5±0.6** MeV/c^2

width: **30.5±1.0±0.9** MeV

ϕ: **2.35±0.05±0.04** rad

η_c: comparison with earlier measurements

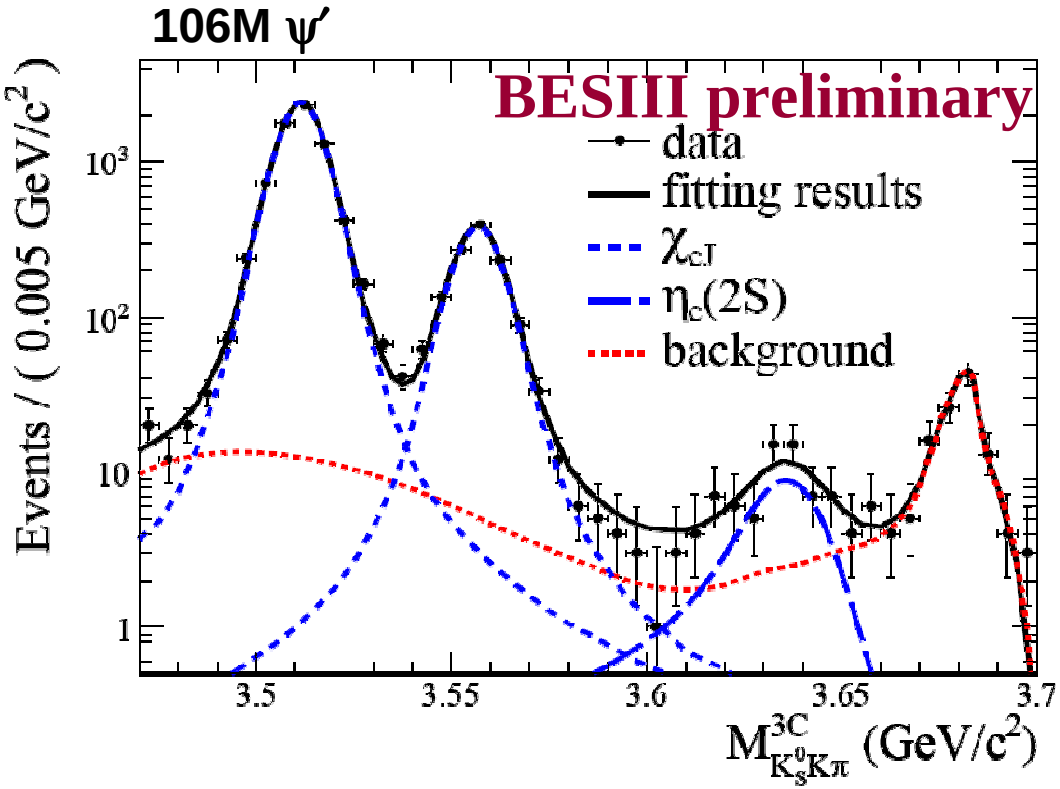




Mass: **2984.4±0.5±0.6** MeV/*c2*
width: **30.5±1.0±0.9** MeV

Currently is the most precise measurement

First observation of $\psi' \to \gamma\eta_c(2S)$



Width fixed to 12 MeV (world ave.)

Events: **50.6±9.7**; Significance >6.0σ!

Mass = **3638.5±2.3±1.0** MeV/c^2

$BF(\psi' \to \gamma\eta_c(2S) \to \gamma K_S K\pi)$
$=(2.98\pm0.57\pm0.48)\times10^{-6}$

$BF(\eta_c(2S) \to \bar{K}K\pi)=(\mathbf{1.9\pm0.4\pm1.1})\%$
BaBar: PR D78 012006 (2008)

$BF(\psi' \to \gamma\eta_c(2S))$
$= (4.7\pm0.9\pm3.0)\times10^{-4}$

CLEOc: **$<7.6\times10^{-4}$**
PR D81 052002 (2010)

Potential model predicts
$(0.1\text{-}6.2)\times10^{-4}$
PRL 89 162002 (2002)

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

- Important for testing various phenomenological mechanisms: VMD model, $\eta_c - \eta^{(')}$ 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 (~2.2×10^{-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)

$\psi' \to \gamma P$ ($P=\pi^0$, 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
$\to \gamma\eta'(\pi^+\pi^-\gamma)$	$129 \pm 3 \pm 8$		

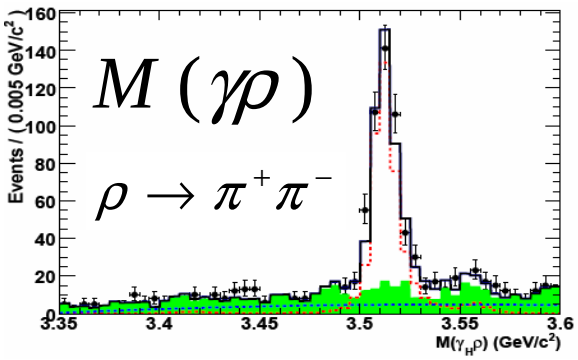
Branching Ratios (x 10^{-6})

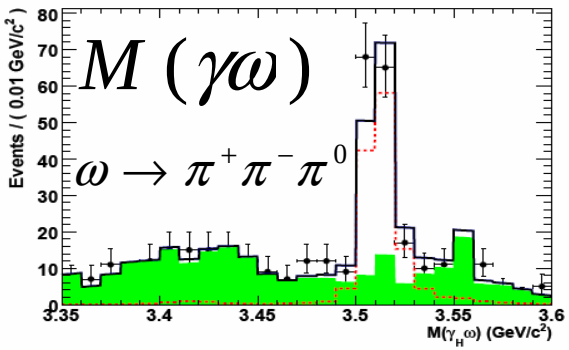
- **Measured branching ratios of $\psi' \to \gamma\eta$ and $\psi' \to \gamma\pi^0$ for the first time**
- **The first measurement of $R_{\psi'} = (1.10 \pm 0.38 \pm 0.07)\%$**
- **Confirmed $R_{\psi'} << R_{J/\psi}$**

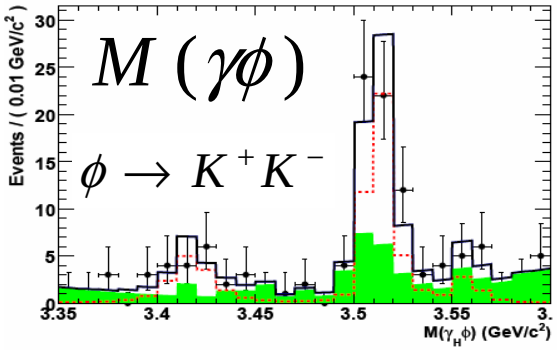
$R_{\psi'} << R_{J/\psi}$ poses a significant challenge to theory.

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

Phys. Rev. D 83, 112005 (2011)



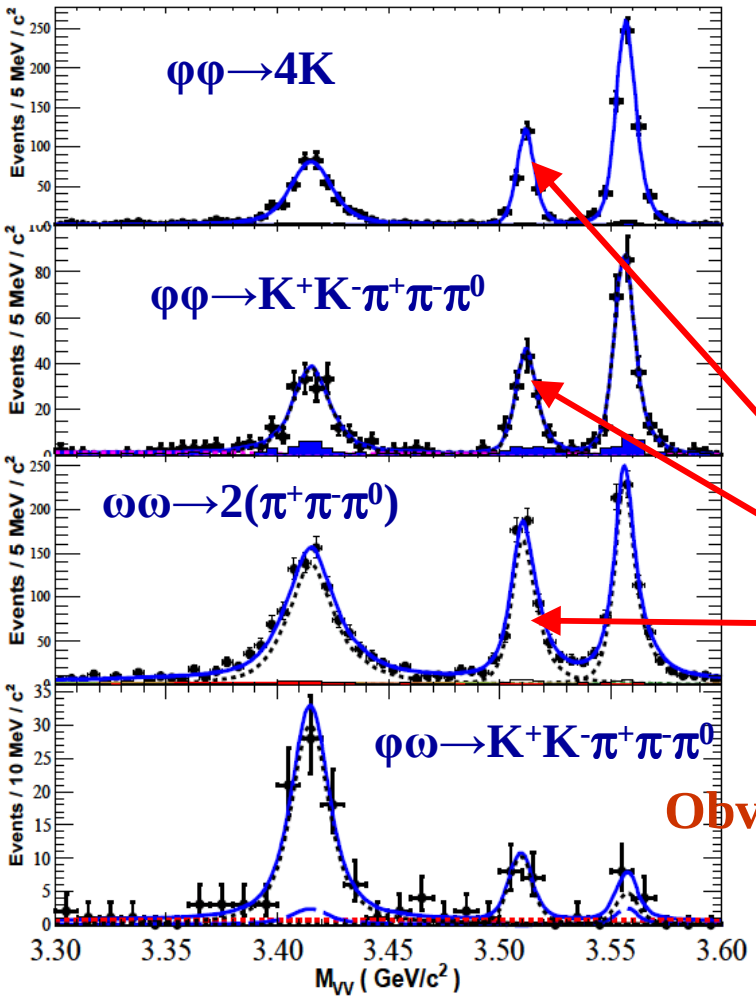




Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]	**BESIII**
$\chi_{c0} \to \gamma\rho^0$	< 9.6	1.2	3.2	2.0	**<10.5**
$\chi_{c1} \to \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42	**228±13±16**
$\chi_{c2} \to \gamma\rho^0$	< 50	4.4	13	38	**<20.8**
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22	**<12.9**
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	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**

First observation

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



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

surprisingly large and clear χ_{c1} signal

Obvious $\varphi\omega$ signal

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

Final states	Channel	N_{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**

Summary

- BES-III is in good shape and will remain the main source of experimental data in tau-charm domain for the next 5-10 years
- World largest samples of J/ψ, ψ', ψ(3770) and ψ(4040) are already collected
- Many the world best measurements in charmonium and light hadron physics was reported, and a number of observation were made for the first time
- Some of BESIII results are quite unexpected
- More new results will come soon

- Charmonium Spectroscopy and Transitions
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi' \to \gamma\gamma J/\psi$ *(to be submitted soon)*
- Charmonium Decays
  - $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\varphi$ *(PRD83,112005(2011))*
  - $\chi_{cJ} \to \omega\omega, \varphi\varphi, \omega\varphi$ *(PRL 107, 092001(2011))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - $\chi_{cJ} \to ppK^+K^-$ (PRD 83, 112009(2011))
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(PRD 83, 012003 (2011))*
  - *Search for* CP/P *violation process pseudoscalar decays into pipi* (PRD 84, 032006(2011)).
- Light Quark States
  - $a_0(980) - f_0(980)$ mixing *(PRD 83, 032003 (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))*
  - X(1870) in $J/\psi \to \omega\eta\pi^+\pi^-$ *(accepted by PRL)*
  - *PWA on* $J/\psi \to \gamma pp$ *(to be submitted soon)*
  - *PWA on* $\psi' \to \eta pp$ *(to be submitted soon)*

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