

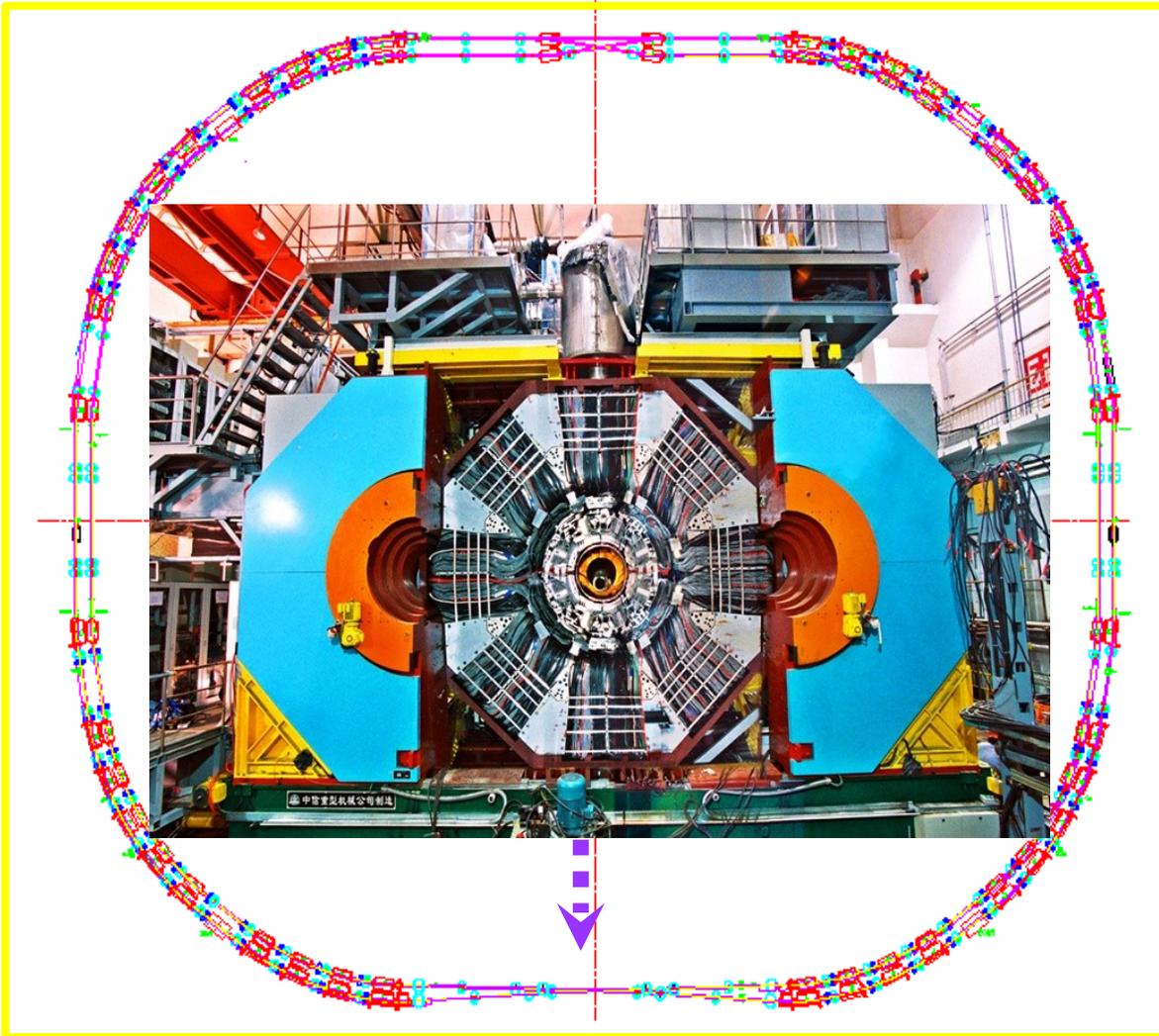
Study of the charmonium spectroscopy at BESIII

Alexey Zhemchugov
(JINR, Dubna)

on behalf of the BES-III Collaboration

The BEPCII/BESIII project

China, Germany, Italy, Japan, JINR,
Korea, Netherlands, Pakistan, Russia,
Turkey, USA



Beam energy:

1.0-2.3 GeV

Design luminosity

$1 \times 10^{33} / \text{cm}^2 / \text{s}$ @ $\psi(3770)$

Achieved luminosity:

$0.65 \times 10^{33} / \text{cm}^2 / \text{s}$

Data samples since 2009:

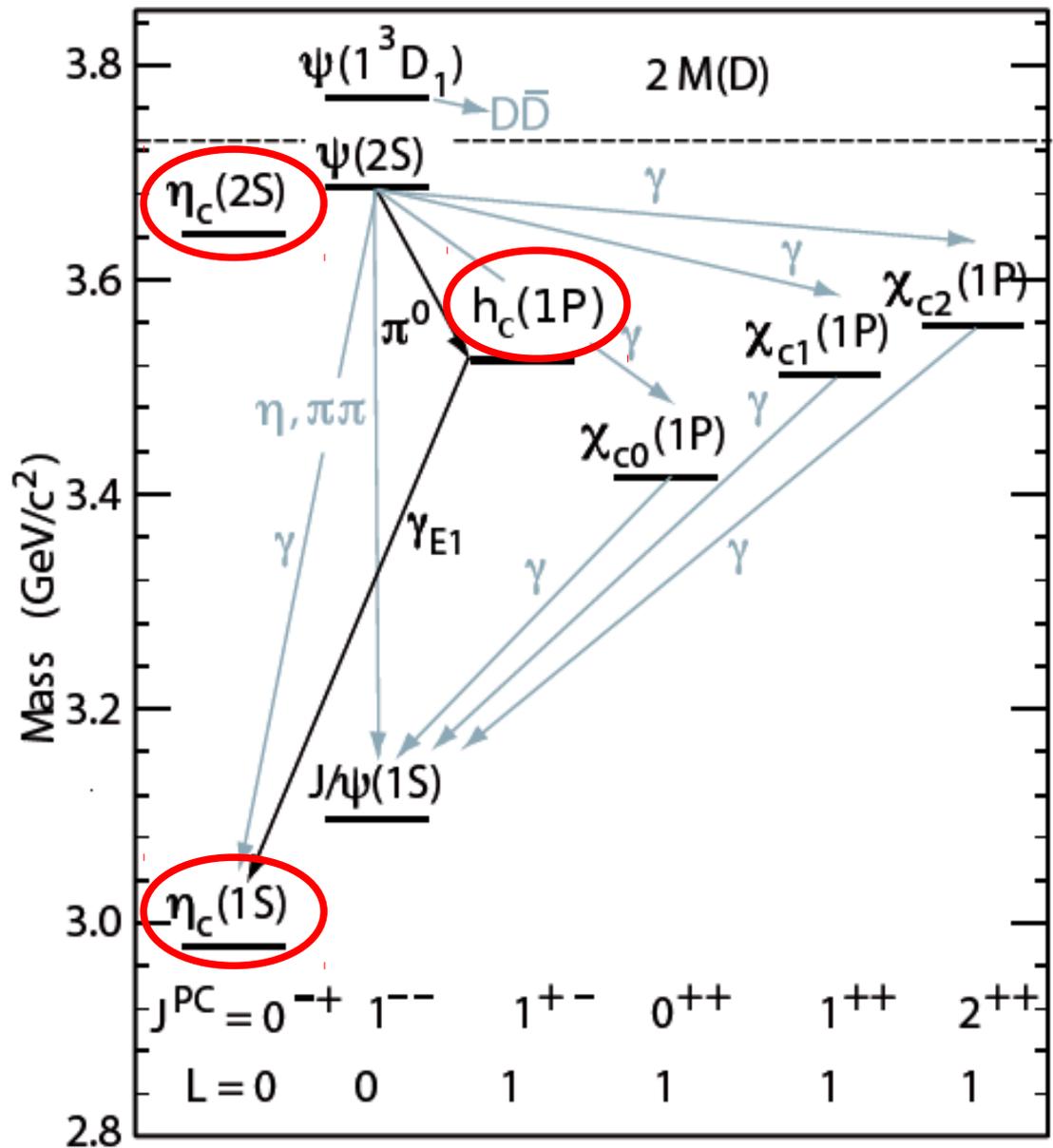
225 Million J/ψ

106 Million ψ'

2.9 fb^{-1} @ $\psi(3770)$

0.47 fb^{-1} @ $\psi(4040)$

Recent BES-III results



h_c

The least studied charmonium state below DD threshold

- $B(\psi' \rightarrow \pi^0 h_c)$ 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
- Large branching of E1 radiation transition
- Theory predictions for $B(h_c \rightarrow \gamma \eta_c)$ vary by factor ~ 2
 - PQCD $(88 \pm 2)\%$
 - NRQCD $(41 \pm 3)\%$

Kuang, PRD 65 (2002) 094024
- Before BES-III only combined branching $B(\psi' \rightarrow \pi^0 h_c) \times B(h_c \rightarrow \gamma \eta_c)$ was measured (CLEO-c, 2008) - consistent with both approaches

Properties of h_c at BESIII

$$\psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$$

PRL104, 132002 (2010)

Inclusive

$$\text{Br}(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$$

E1-tagged

$$M(h_c) = 3525.40 \pm 0.13 \pm 0.18 \text{ MeV}$$

$$(\Delta M_{\text{hf}}(1P) = 0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2)$$

$$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}$$

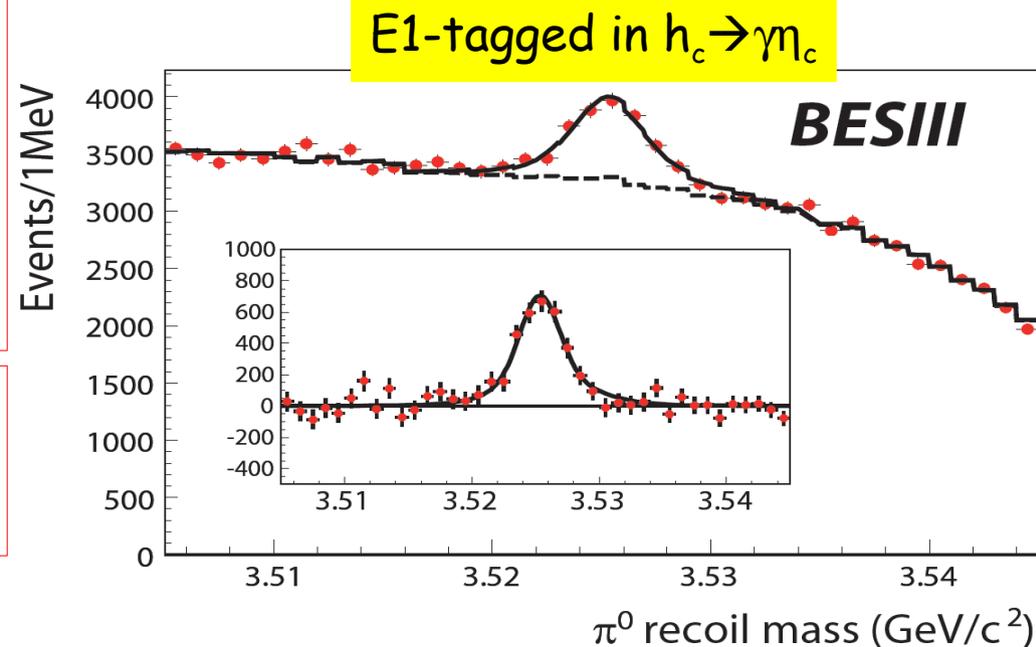
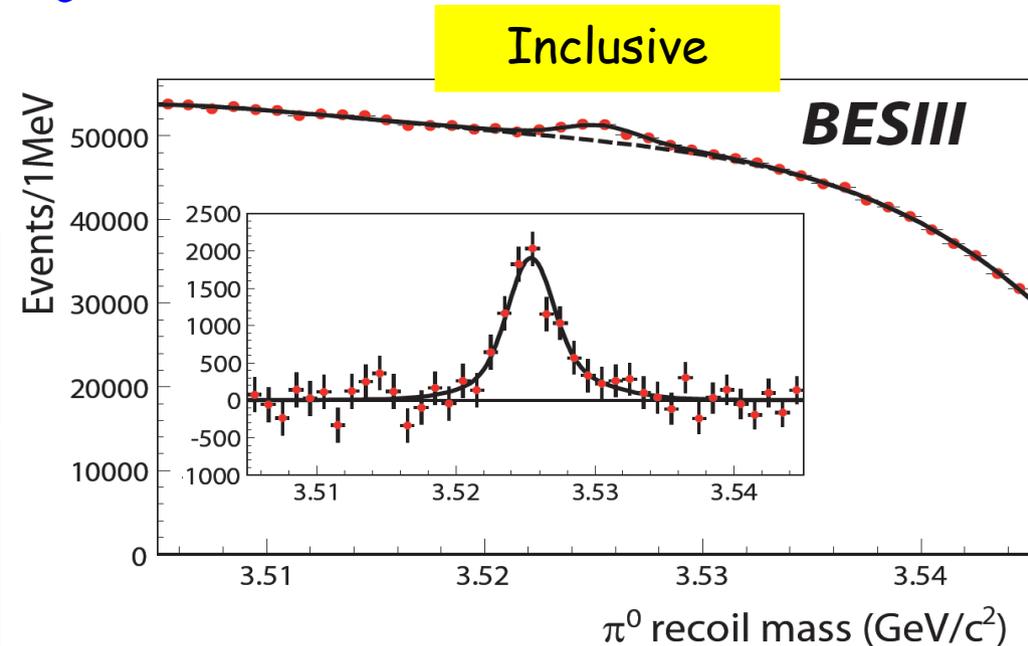
(<1.44 MeV at 90% CL)

$$\text{Br}(\psi' \rightarrow \pi^0 h_c) \times \text{Br}(h_c \rightarrow \gamma \eta_c) =$$

$$(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$$

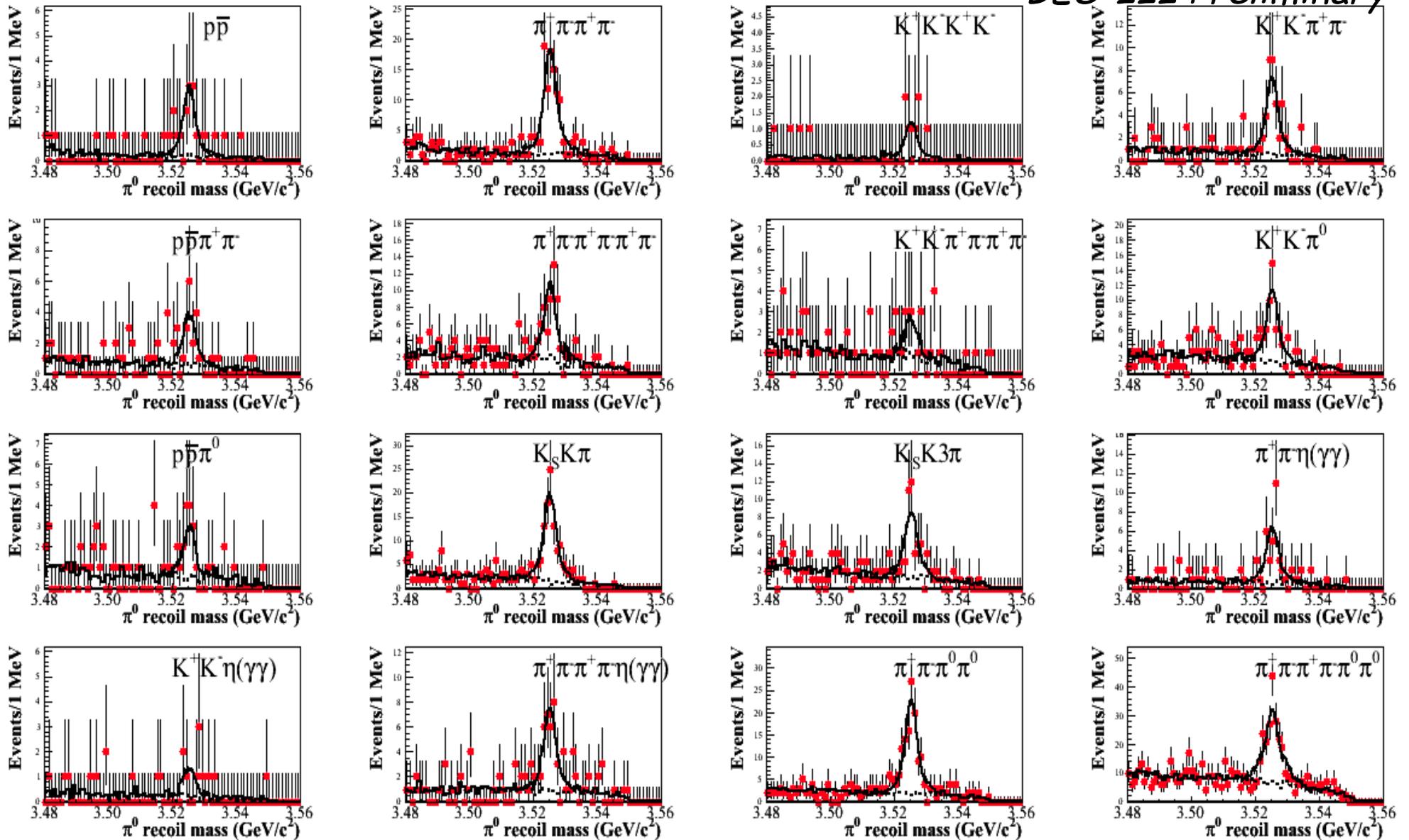
Combined

$$\text{Br}(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$$

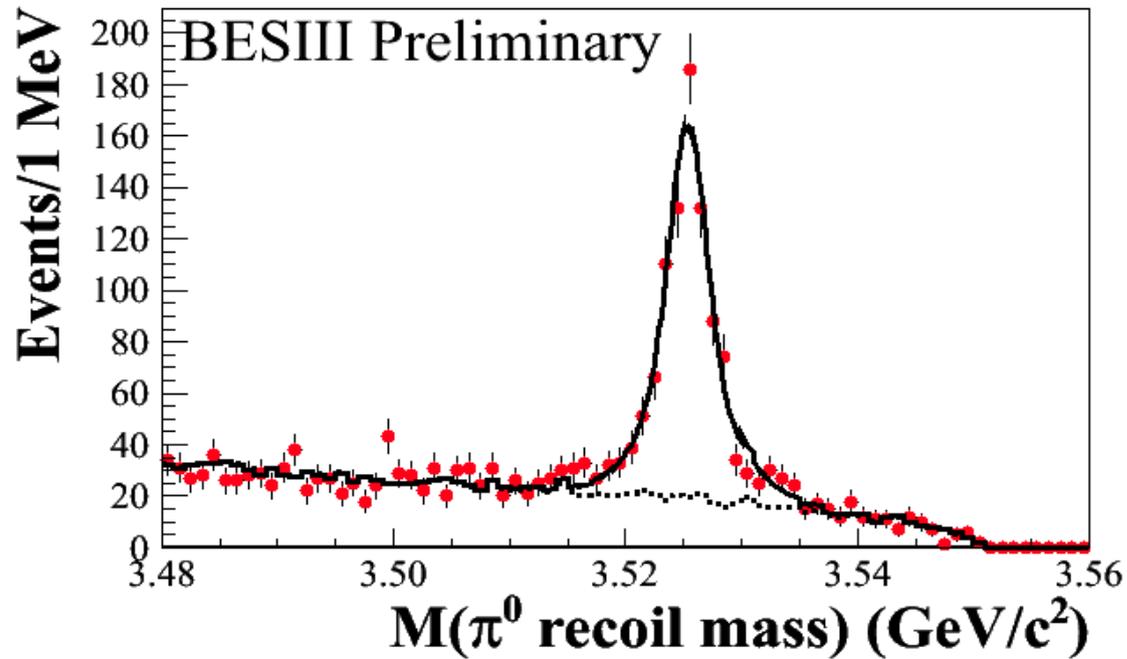


Exclusive measurement $\psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$

BES-III Preliminary



Exclusive measurement $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$



$$M(h_c) = 3525.31 \pm 0.11 \pm 0.15 \text{ MeV}$$

$$\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.25 \text{ MeV}$$

$$N_{ev} = 832 \pm 35 \quad \text{BES-III Preliminary}$$

h_c : summary

First measurements of $\Gamma(h_c)$, $\text{Br}(\psi' \rightarrow \pi^0 h_c)$ and $\text{Br}(h_c \rightarrow \gamma \eta_c)$

Hyperfine splitting $\Delta M_{\text{hf}}(^1P)$ is compatible with zero

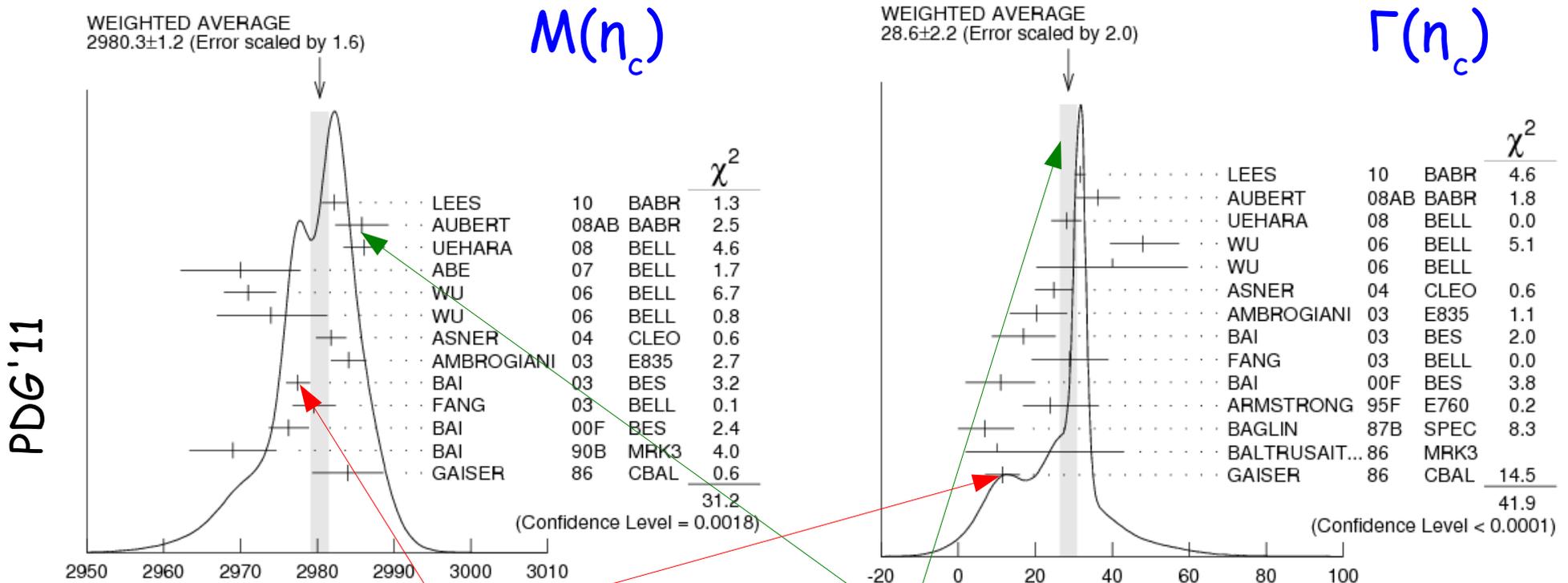
	BES III <i>PRL 104, 132002</i>	CLEO-c <i>PRL 101, 182003</i>
$\text{Br}(\psi' \rightarrow \pi^0 h_c) \times \text{Br}(h_c \rightarrow \gamma \eta_c) \times 10^{-4}$	4.58 ± 0.40 ± 0.50	4.16 ± 0.30 ± 0.37
M [MeV/c ²]	3525.40 ± 0.13 ± 0.18	3525.20 ± 0.18 ± 0.12
$\Delta M_{\text{hf}}(^1P)$ [MeV/c ²]	0.10 ± 0.13 ± 0.18	0.08 ± 0.18 ± 0.12
		Theoretical predictions
$\Gamma(h_c)$ [MeV]	0.73 ± 0.45 ± 0.28 < 1.44 @ 90%CL	1.1 (NRQCD) Kuang 0.51 (PQCD) Kuang
$\text{Br}(h_c \rightarrow \gamma \eta_c)$ [%]	54.3 ± 6.7 ± 5.2	41 (NRQCD) Kuang 88 (PQCD) Kuang 38 Godfrey, Rosner
$\text{Br}(\psi' \rightarrow \pi^0 h_c) \times 10^{-4}$	8.4 ± 1.3 ± 1.0	4 - 13 Kuang

Kuang, PRD65, 094024 (2002)

Godfrey & Rosner, PRD 66, 014012 (2002)

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}



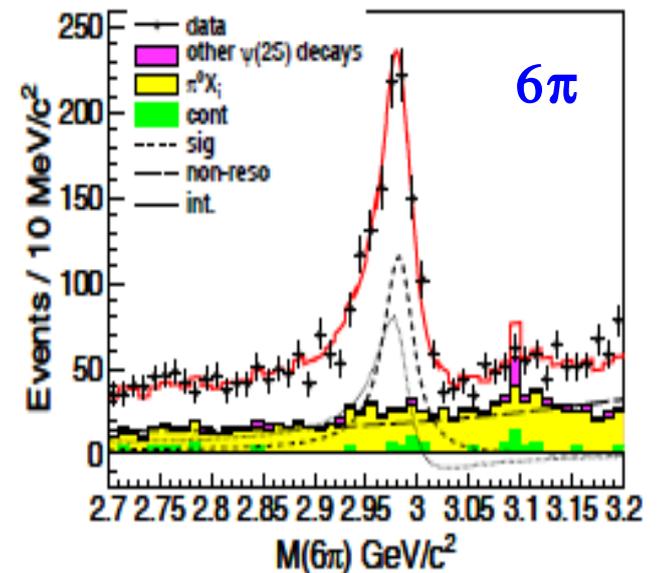
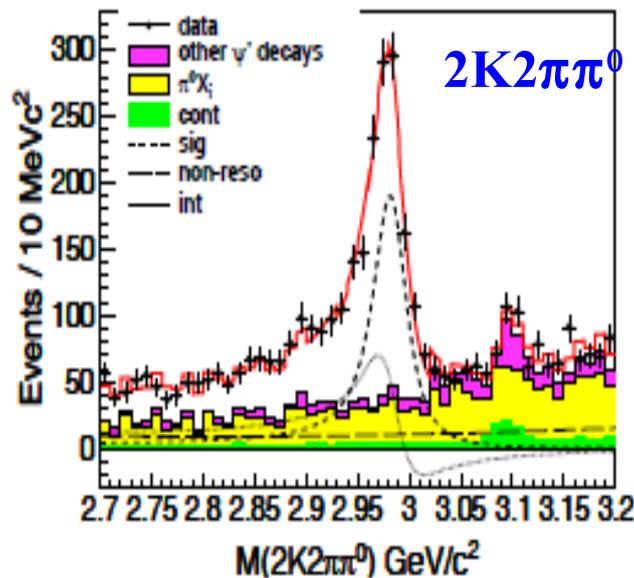
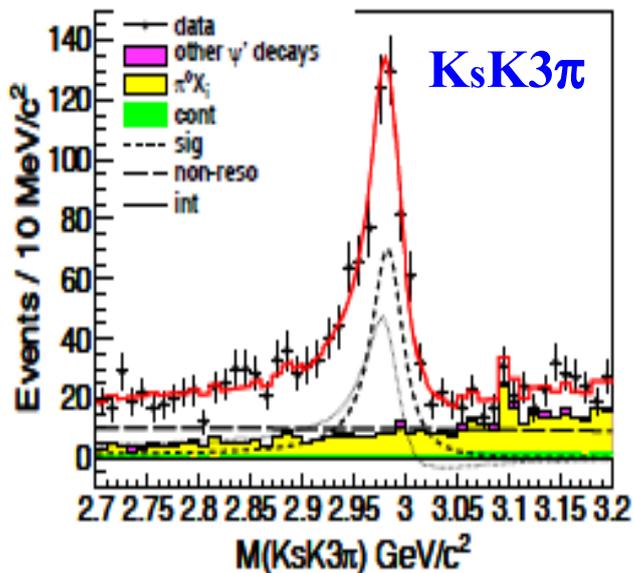
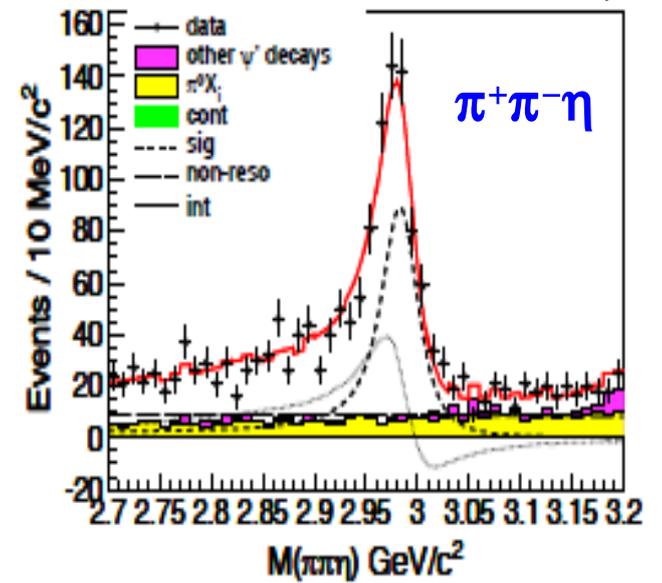
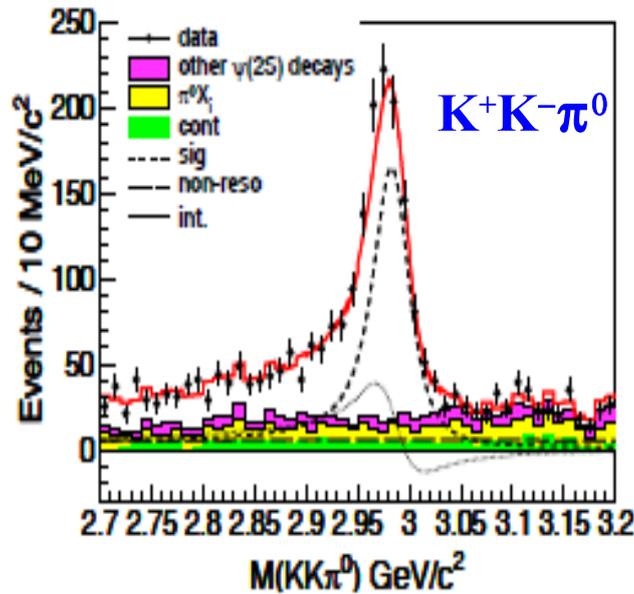
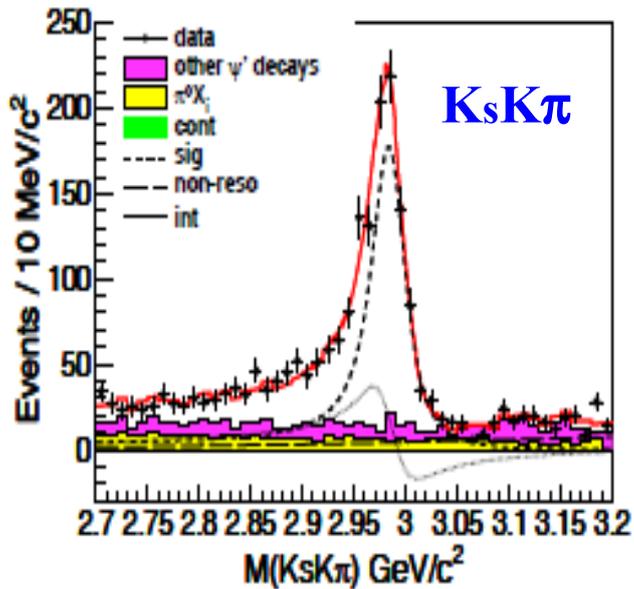
J/ ψ radiative transition:
 $M(\eta_c) \sim 2978.0 \text{ MeV}$
 $\Gamma(\eta_c) \sim 10 \text{ MeV}$

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

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

η_c from $\psi' \rightarrow \gamma \eta_c$ at BES-III

BES-III Preliminary



The simultaneous fit

- Fit takes into account **interference** between η_c and non- η_c decays
- Modified BW is used (M1 transition taken into account)
- Mass and width of η_c and interference phase ϕ are constrained to be the same

BESIII preliminary

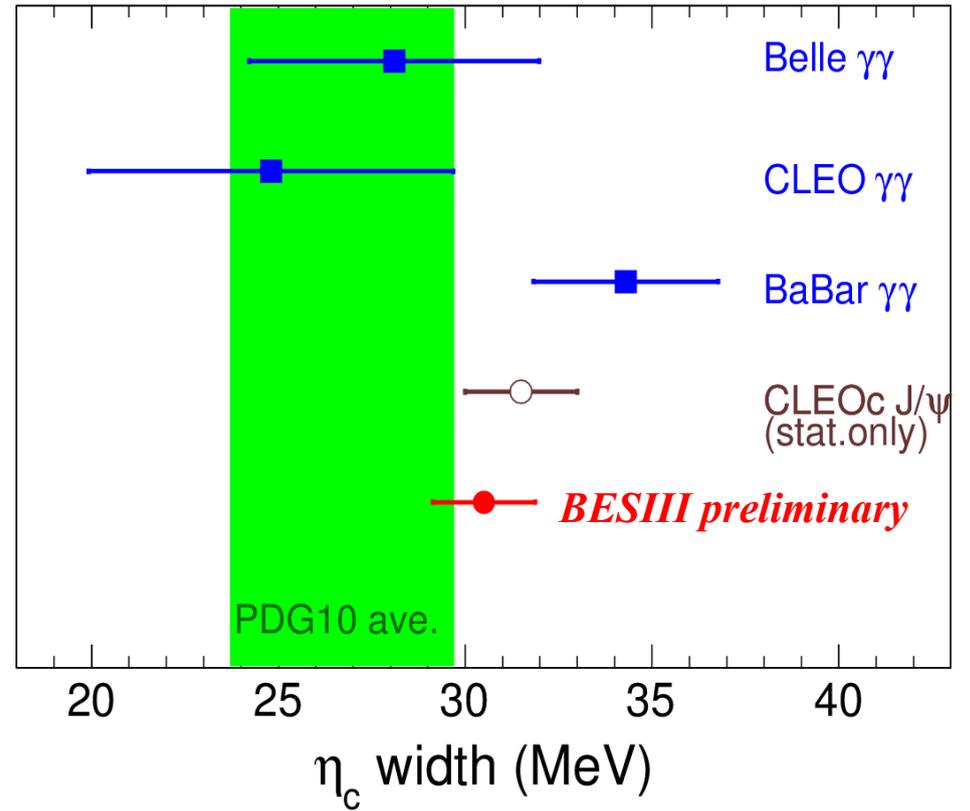
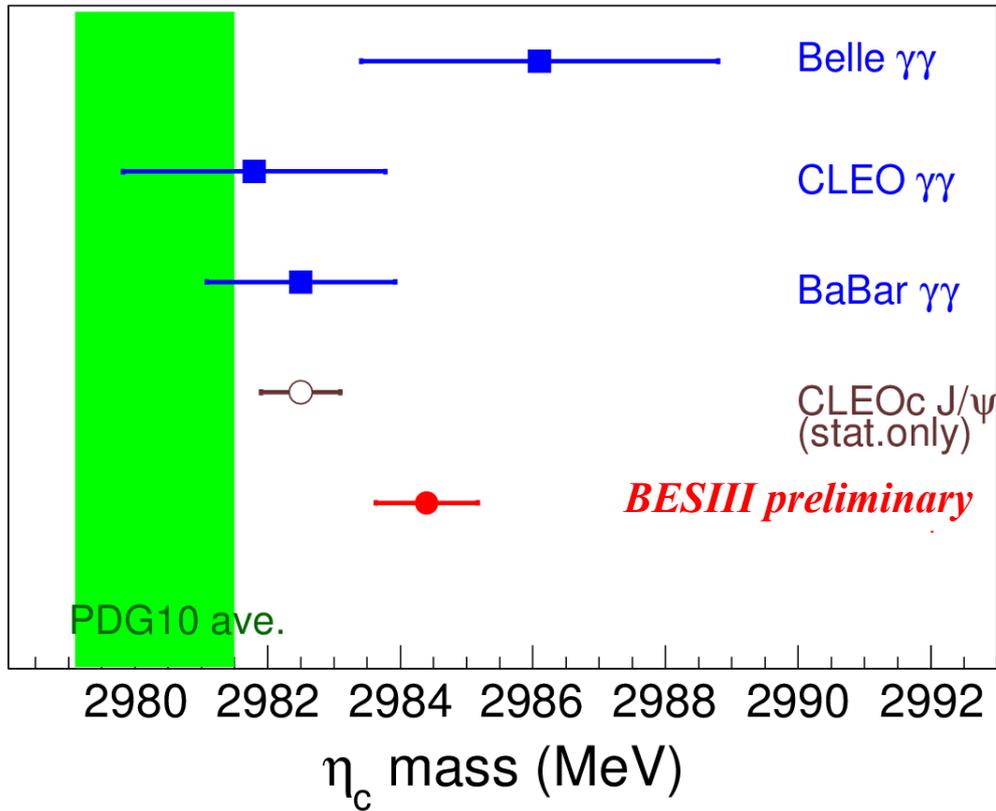
$$M(\eta_c) = 2984.4 \pm 0.5_{\text{stat}} \pm 0.6_{\text{sys}} \text{ MeV}$$

$$\Gamma(\eta_c) = 30.5 \pm 1.0_{\text{stat}} \pm 0.9_{\text{sys}} \text{ MeV}$$

$$\phi = 2.35 \pm 0.05_{\text{stat}} \pm 0.04_{\text{sys}} \text{ rad}$$

Currently the most precise measurement!

Comparison with earlier measurements



$\eta_c(2S)$ in ψ' decays

- $\eta_c(2S)$ was observed in only B decays and two-photon processes so far

- Current PDG values:

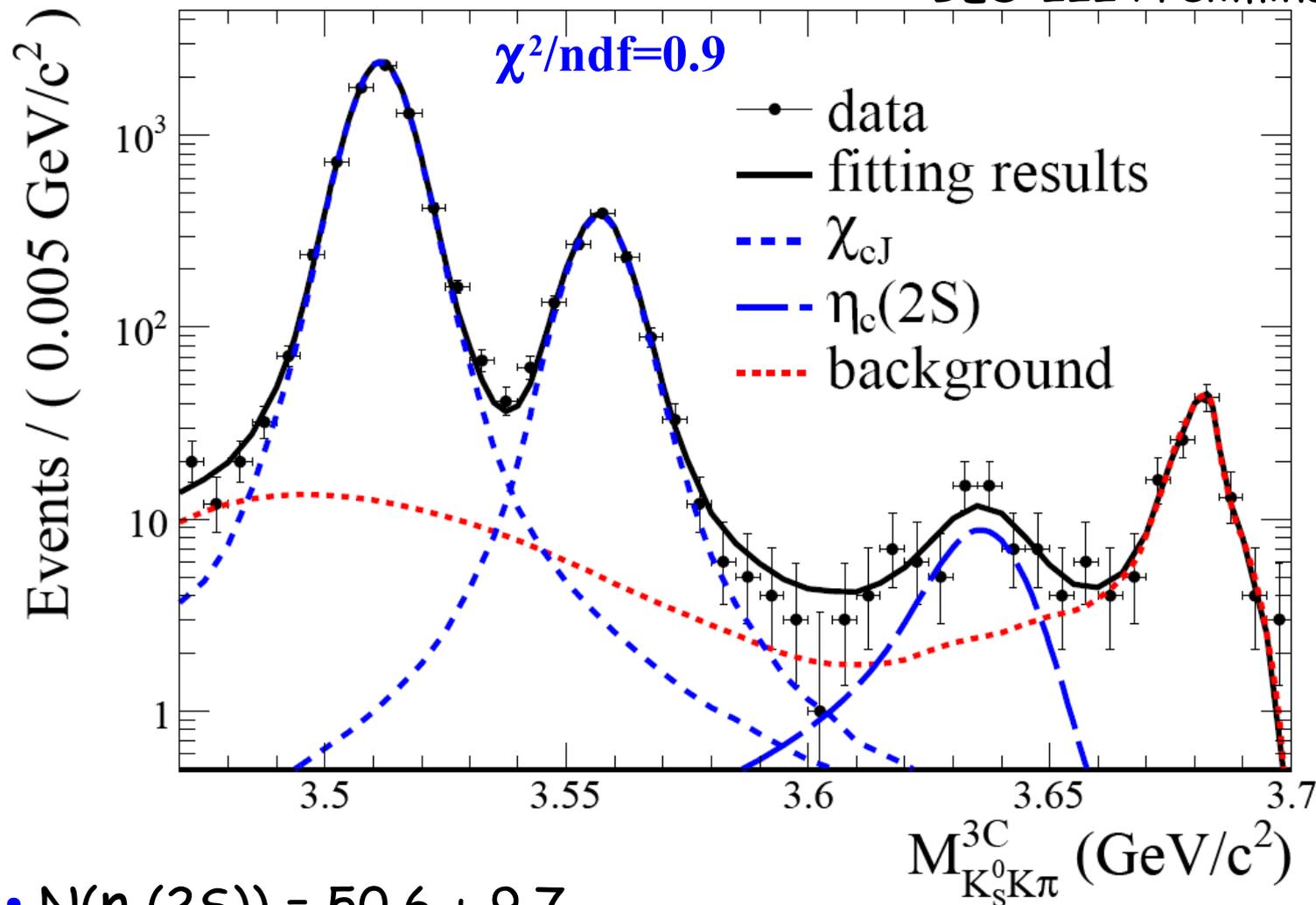
$$M(\eta_c(2S)) = 3637 \pm 4 \text{ MeV}$$

$$\Gamma(\eta_c(2S)) = 14 \pm 7 \text{ MeV}$$

- Was searched in $\psi' \rightarrow \gamma \eta_c(2S) \rightarrow \gamma K_s K \pi$ at BES-III

First observation of M1 transition $\psi' \rightarrow \eta_c(2S)$

BES-III Preliminary



- $N(\eta_c(2S)) = 50.6 \pm 9.7$
- Pure statistical significance more than 6σ
- Significance with systematic variations not less than 5σ

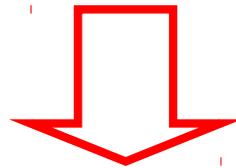
$\eta_c(2S)$ @ BES-III

BES-III Preliminary

$$M(\eta_c(2S)) = 3638.5 \pm 2.3_{\text{stat}} \pm 1.0_{\text{sys}} \text{ (MeV/c}^2\text{)}$$

$$\text{Br}(\psi' \rightarrow \gamma \eta_c(2S) \rightarrow \gamma K_s K \pi) = (2.98 \pm 0.57_{\text{stat}} \pm 0.48_{\text{sys}}) \times 10^{-6}$$

BaBar: $\text{Br}(\eta_c(2S) \rightarrow K K \pi) = (1.9 \pm 0.4 \pm 1.1)\%$



BES-III Preliminary

$$\text{Br}(\psi' \rightarrow \gamma \eta_c(2S)) = (4.7 \pm 0.9_{\text{stat}} \pm 3.0_{\text{sys}}) \times 10^{-4}$$

CLEO-c: $< 7.6 \times 10^{-4}$ (PRD81,052002(2010))

Potential model: $(0.1 - 6.2) \times 10^{-4}$ (PRL89,162002(2002))

Nearest future

- 470 pb⁻¹ at $\Psi(4040)$ taken already
 - *Search for XYZ states*
 - *Hadronic transitions of $\Psi(4040)$*
 - *Radiative transitions of $\Psi(4040)$*
- 0.7B $\Psi(2S)$ are expected in 2012

Summary

- Charmonium spectroscopy at BES-III benefits from the high luminosity of BEPCII and from the good detector performance
- Mass, width of h_c and $\text{Br}(\psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c)$ measured (inclusive & exclusive). Width and branchings measured for the first time.
- Properties of η_c precisely measured at BESIII. The observed distortion of η_c lineshape described successfully by an interference.
- The M1 transition $\psi' \rightarrow \gamma \eta_c(2S)$ observed for the first time
- Much more results on the charmonium spectroscopy are expected from the largest $\psi(4040)$ sample and from increased ψ' sample to be taken next year.

Mass fitting

➤ $\eta_c(2S)$ signal:

$\Gamma(\eta_c(2S))$ fixed to 12MeV (world average)

$$(E_\gamma^3 \times BW(m) \times \text{damping}(E_\gamma)) \otimes \text{Gauss}(0, \sigma)$$

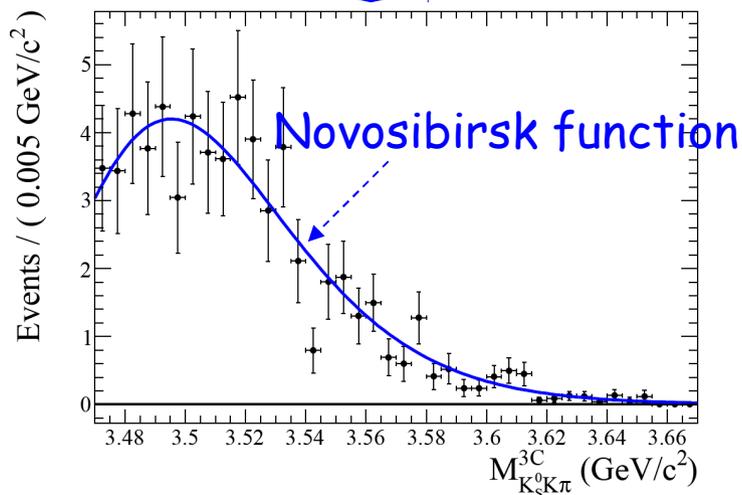
M1 transition

$$\frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2} \text{ Fixed to the linear extrapolation from } \sigma(\chi_{cJ})$$

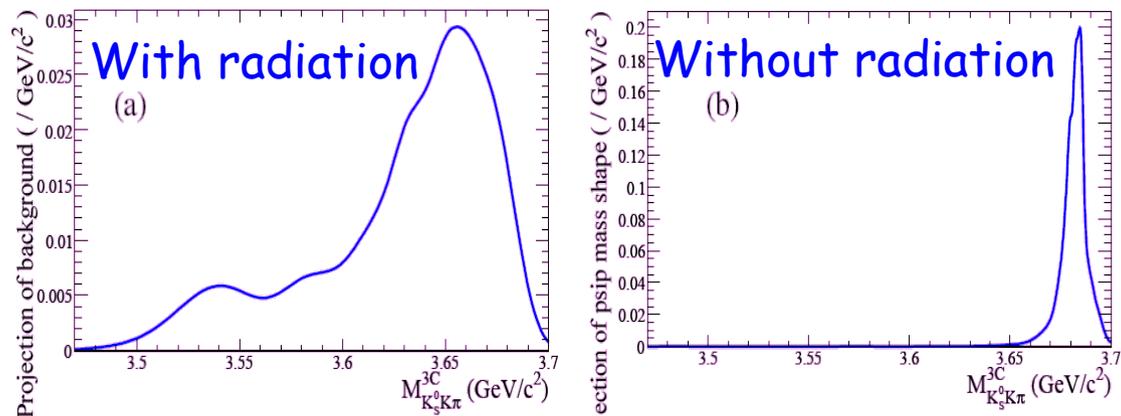
➤ χ_{cJ} : MC shape \otimes a Gaussian

➤ BG from $\pi^0 K_S K \pi$:

Measurement + scaling with MC simulation



➤ BG from $\psi' \rightarrow K_S K \pi (\gamma_{\text{FSR}})$ & continuum ($K_S K \pi (\gamma_{\text{ISR}})$):



Ratio of the two is fixed in the final mass fitting