

Recent Charmonium Results from BESIII

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(for BESIII Collaboration)

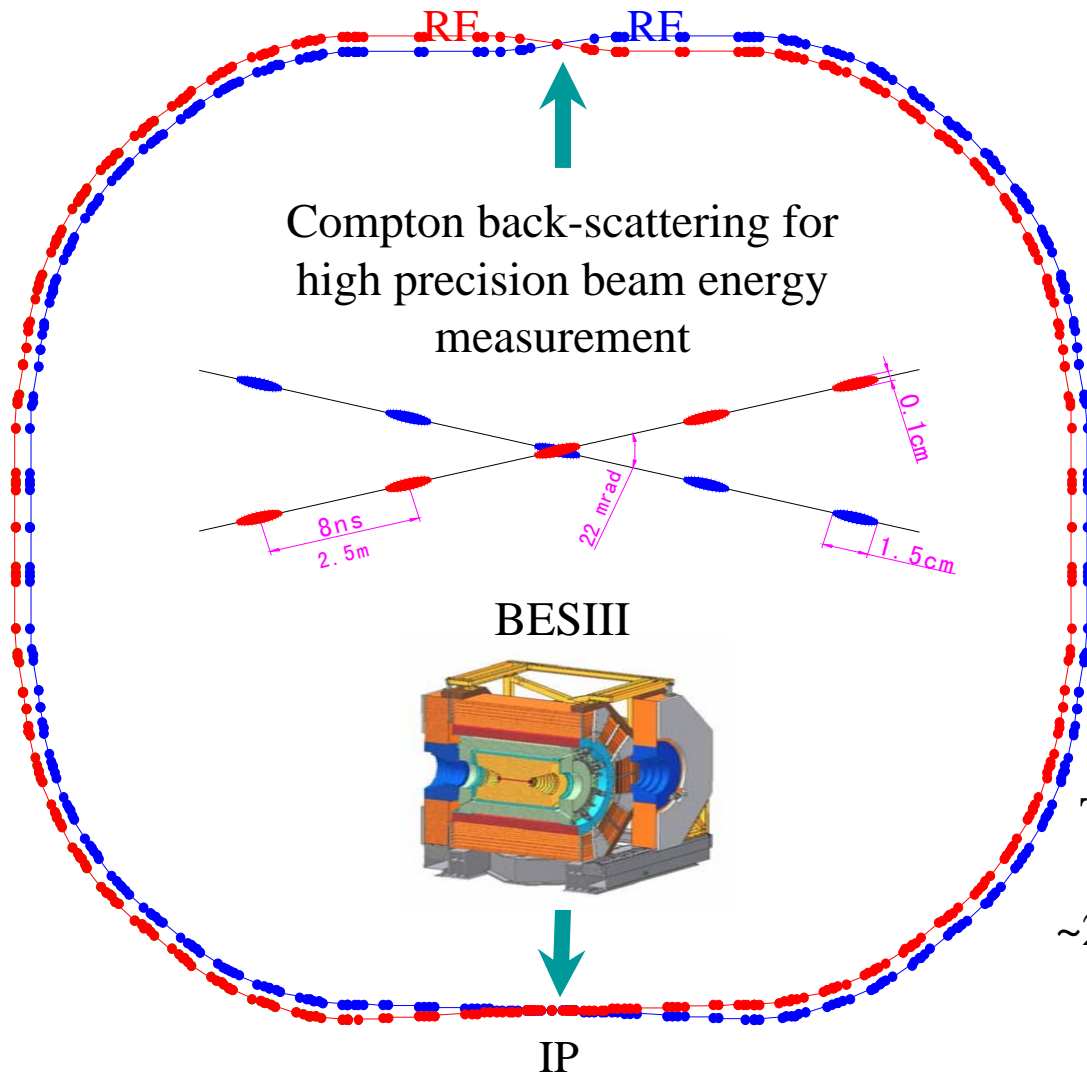
Nankai University & Institute of High Energy Physics

The 24th Rencontres de Blois, 27th May – 1st Jun, 2012

Outline

- Introduction of BEPCII and BESIII
- Results presented in this talk:
 - h_c : the singlet 1P state discovered most recently, new measurements of the properties and the production
 - η_c : the lightest charmonium state, precision measurement of the properties and the distorted lineshape
 - η_c' : first observation in charmonium transitions and new decay mode study
 - **Magnetic dipole** component of $\psi' \rightarrow \gamma \chi_{c2}$
- Summary

BEPCII and BESIII



BEPCII: double-ring

Beam energy: 1-2.3 GeV

Designed Luminosity:

$$1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$$

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

BESIII detector:

Helium-based drift chamber:

0.5% @ 1GeV/c, $dE/dx \sim 6\%$

TOF: 80 ps (barrel), 110 ps (endcap)

CsI EM calorimeter:

$\sim 2.5\%$ (barrel), $\sim 5\%$ (endcaps) @ 1GeV

1T Superconducting magnet

Muon system: 9 layers of RPC

BESIII data samples

- 2009: **106 million ψ'**
225 million J/ψ
- 2010: $\sim 900 \text{ pb}^{-1} \psi(3770)$
- 2011: $\sim 1900 \text{ pb}^{-1} \psi(3770)$
 $470 \text{ pb}^{-1} @ 4.01 \text{ GeV}$
- 2012: **~ 0.3 billion ψ'**
 ~ 0.7 billion J/ψ , started from 5th April

First e^+e^- collision event at 19th July, 2008

Peak luminosity reached $0.65 \times 10^{33} @ 3.770 \text{ GeV}$

About $h_c(^1P_1)$

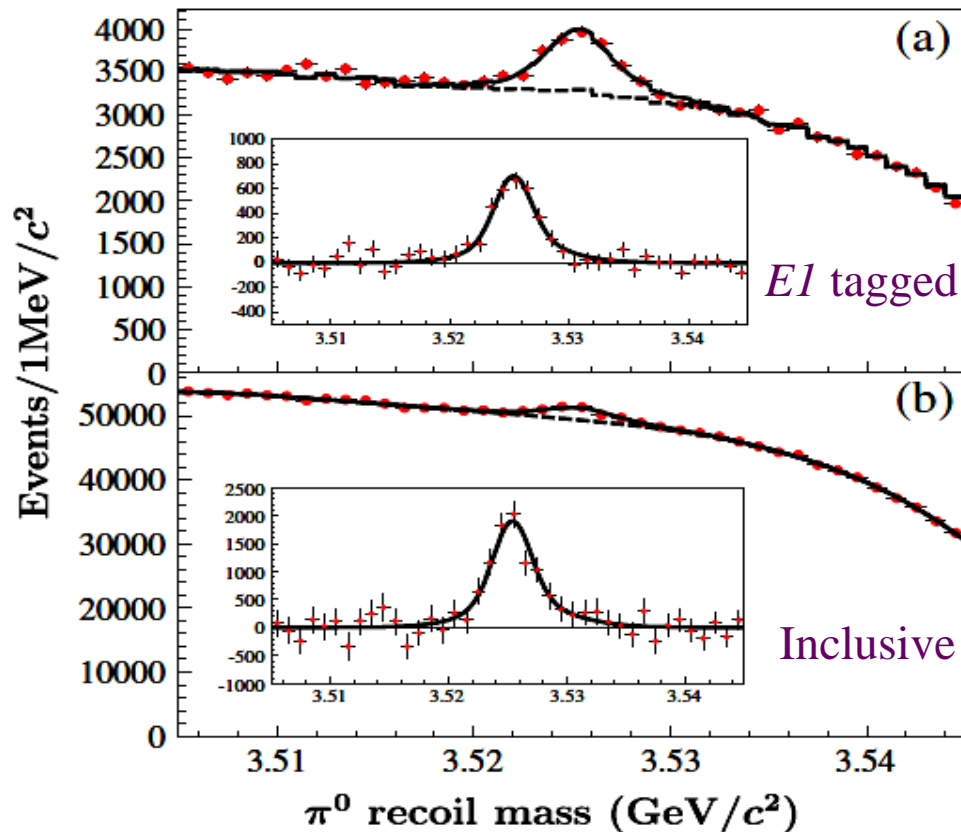
- Spin singlet P wave ($S=0, L=1$)
- First evidence: E835 in $pp \rightarrow h_c \rightarrow \gamma \eta_c$
- Potential model: if non-vanishing P-wave spin-spin interaction,

$$\Delta M_{\text{hf}}(1P) = M(h_c) - \langle M(1^3P_J) \rangle \neq 0,$$
 where $\langle M(1^3P_J) \rangle = [M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2})]/9$
- CLEO-c observed h_c in $e^+e^- \rightarrow \psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$

$$\Delta M_{\text{hf}}(1P) = 0.08 \pm 0.18 \pm 0.12 \text{ MeV}/c^2$$
 (consistent with 1P hyperfine splitting = 0)
- Theoretical predictions:
 - $B(\psi' \rightarrow \pi^0 h_c) = (0.4-1.3) \times 10^{-4}, B(h_c \rightarrow \gamma \eta_c) = 48\%$ (NPQCD)
 $B(h_c \rightarrow \gamma \eta_c) = 88\%$ (PQCD)
Y. P. Kuang, PRD65, 094024 (2002)
 - $B(h_c \rightarrow \gamma \eta_c) = 38\%$ *Godfrey and Rosner, PRD66, 014012 (2002)*

$\psi' \rightarrow \pi^0 h_c$ transition @ BESIII

PRL104, 132002 (2010)



Inclusive: only detect π^0 ($\psi' \rightarrow \pi^0 h_c$)
EI tagged: detect π^0 and γ ($\psi' \rightarrow \pi^0 h_c$,
 $h_c \rightarrow \gamma \eta_c$)

Mass: $3525.40 \pm 0.13 \pm 0.18$ MeV/c²

Width: $0.73 \pm 0.45 \pm 0.28$ MeV

(<1.44 MeV @ 90% C.L.)

$\Delta M_{\text{hf}} = M(h_c) - \langle M(^3P_J) \rangle = 0.10 \pm 0.13$
 ± 0.18 MeV/c²

Agrees with zero within ~ 0.5 MeV

Information on spin-spin interaction.

By combining inclusive results with *EI* tagged results (First measurements)

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

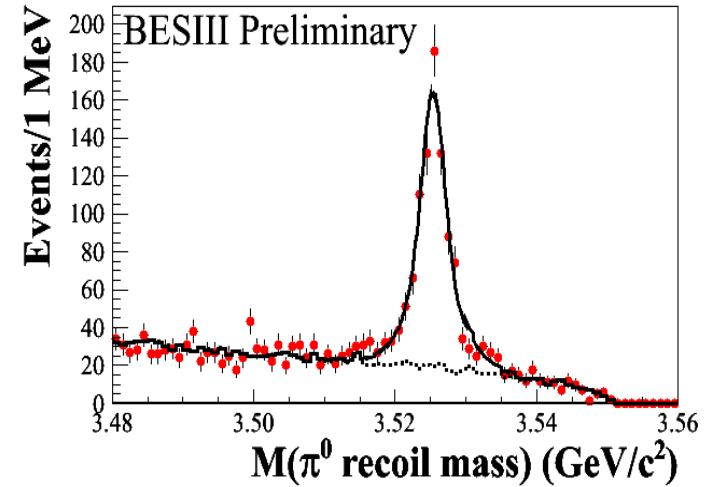
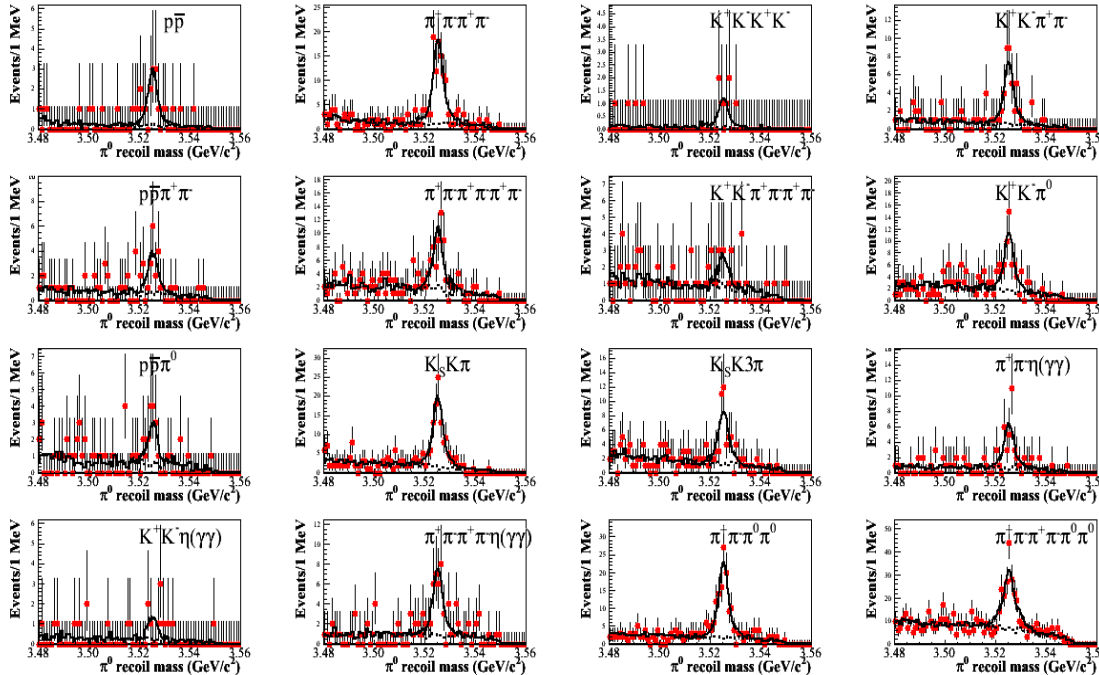
$$B(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2) \%$$

Agree with predictions of Kuang,
 Godfrey, Dudek, et al.

$\psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c, 16 \eta_c$ exclusive decays

BESIII preliminary

Summed π^0 recoil mass



Simultaneous fit to π^0 recoiling mass
 $M(h_c) = 3525.31 \pm 0.11 \pm 0.15 \text{ MeV}/c^2$
 $\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.25 \text{ MeV}$
 $N = 832 \pm 35$
 $\chi^2/\text{d.o.f.} = 32/46$

Consistent with CLEO-c exclusive
 $M(h_c) = 3525.21 \pm 0.27 \pm 0.14 \text{ MeV}/c^2$
 $N = 136 \pm 14$
PRL101, 182003(2008)

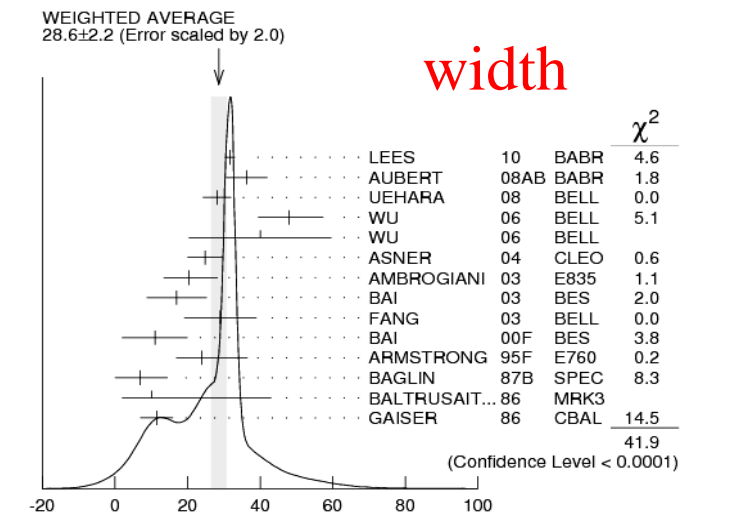
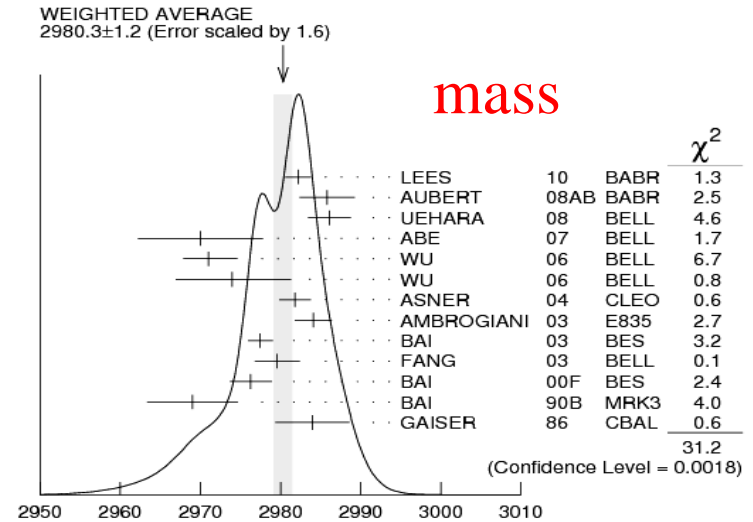
η_c , the lowest lying charmonium state

- Ground state of cc system, but its properties are not well known
- The obvious discrepancy between different experimental results may be due to different experimental production mechanisms

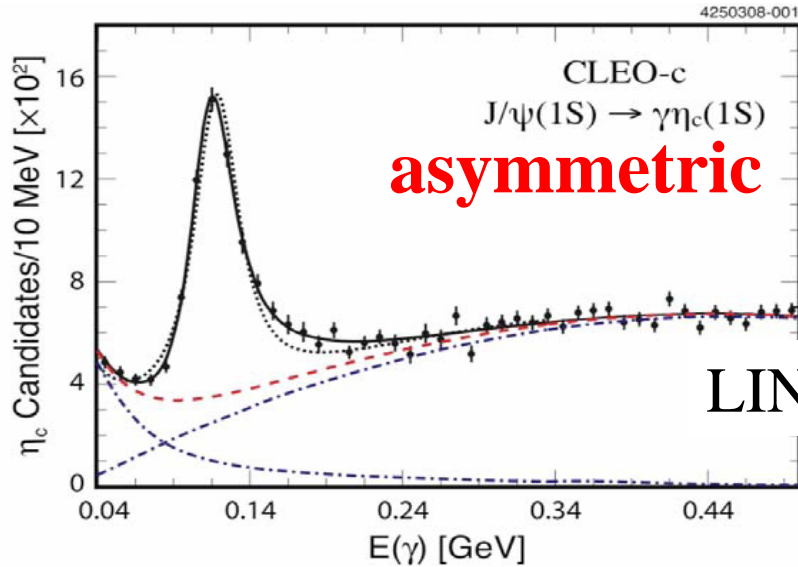
- Charmonium radiative decay
- Two-photon fusion or B decay

• The precision measurement of the mass can provide information on the hyperfine splitting: $M(J/\psi) - M(\eta_c)$

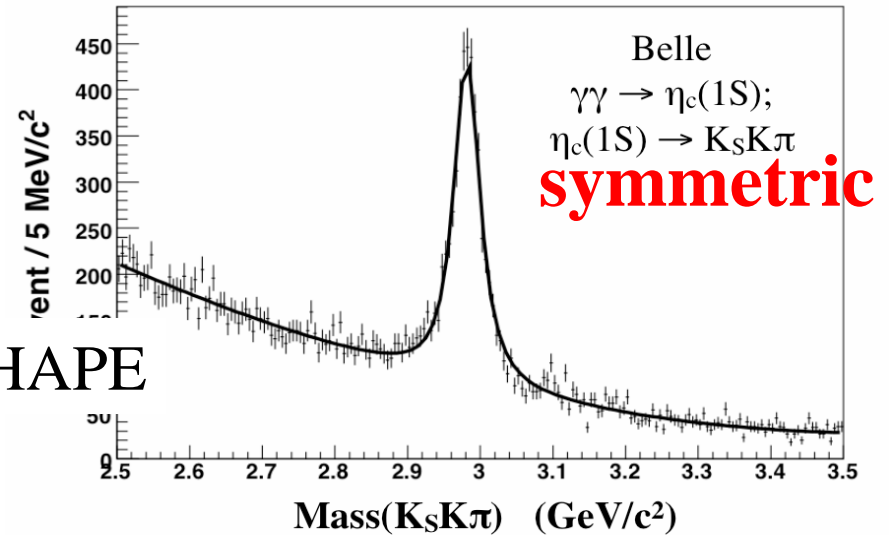
- Important experimental input to tests of lattice QCD



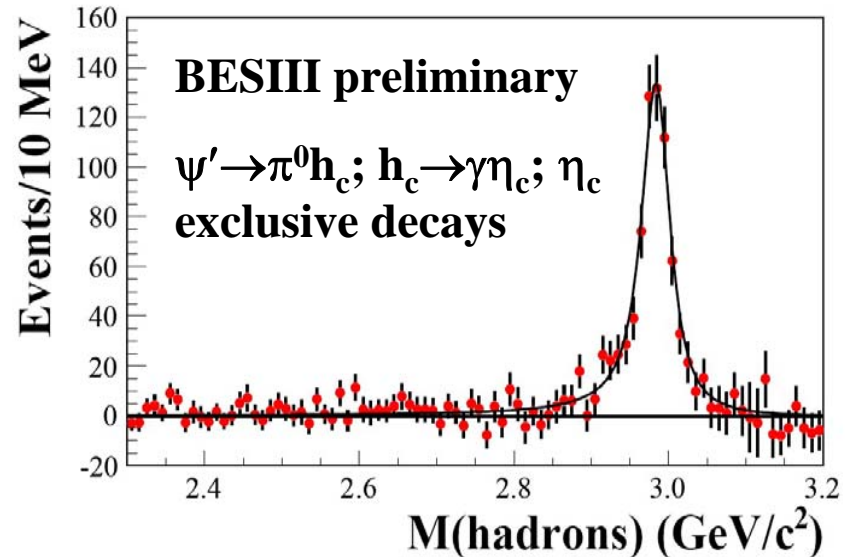
Lineshape of η_c



LINESHAPE

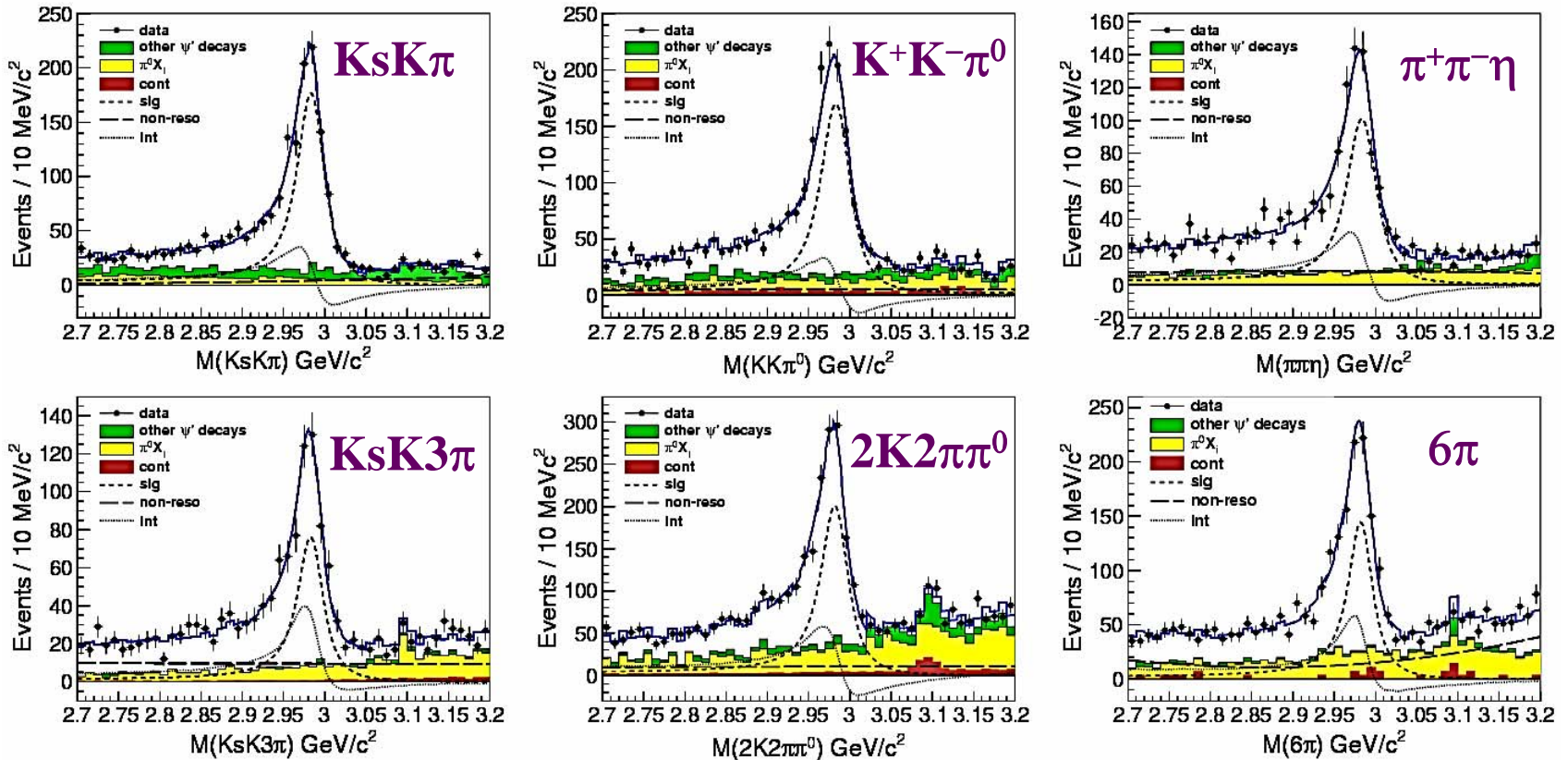


- CLEO-c observed a distortion of η_c lineshape in charmonium radiative decay [*PRL102, 011801 (2009)*]
- The lineshape of η_c from BELLE is symmetric
- The abnormal line shape is also observed in BESIII exclusive channels in $\psi' \rightarrow \gamma\eta_c$ but not in $\psi' \rightarrow \pi^0 h_c; h_c \rightarrow \gamma\eta_c$



η_c resonance parameters from $\psi' \rightarrow \gamma \eta_c$

arXiv:1111.0398, accepted by PRL



Simultaneous fit with modified Breit-Wigner (hindered $M1$) with considering **interference** between η_c and non- η_c decays

Mass and width of η_c

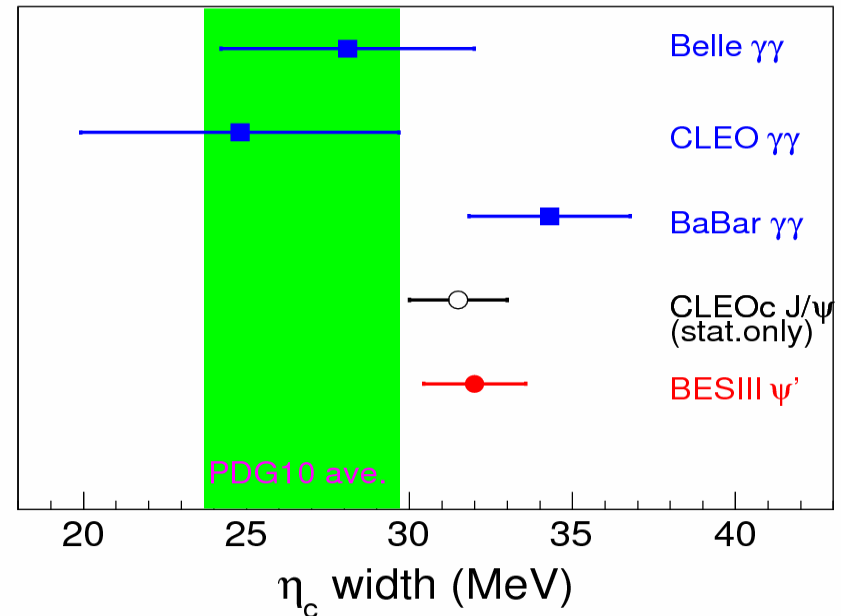
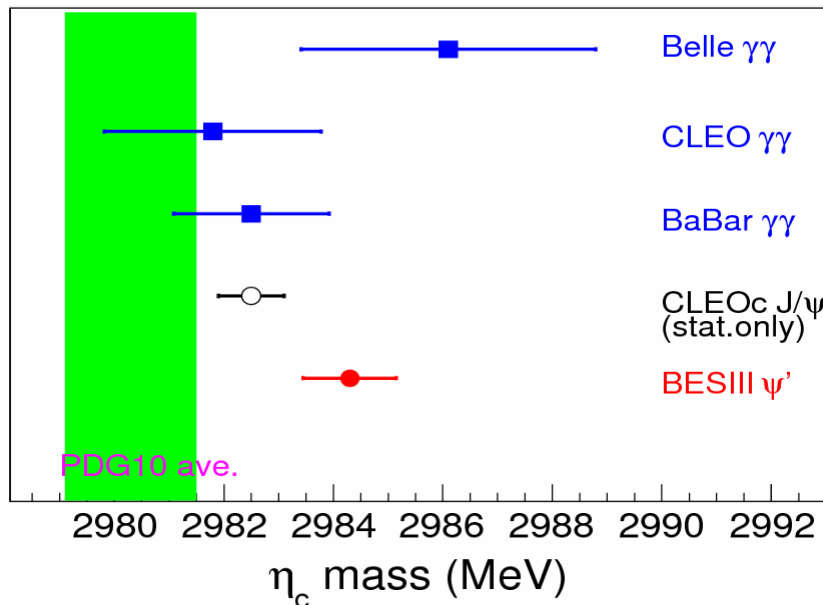
arXiv:1111.0398, Accepted by PRL

Mass = $2984.3 \pm 0.6 \pm 0.6$ MeV/c²

Width = $32.0 \pm 1.2 \pm 1.0$ MeV

$\phi = 2.40 \pm 0.07 \pm 0.08$ rad or $4.19 \pm 0.03 \pm 0.09$ rad (two resolutions of the interference)

World average in PDG2010 uses earlier measurements.

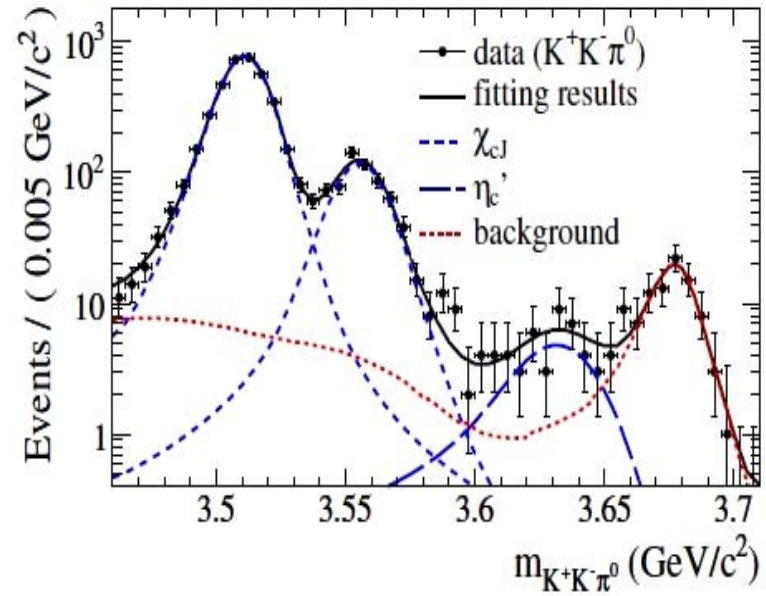
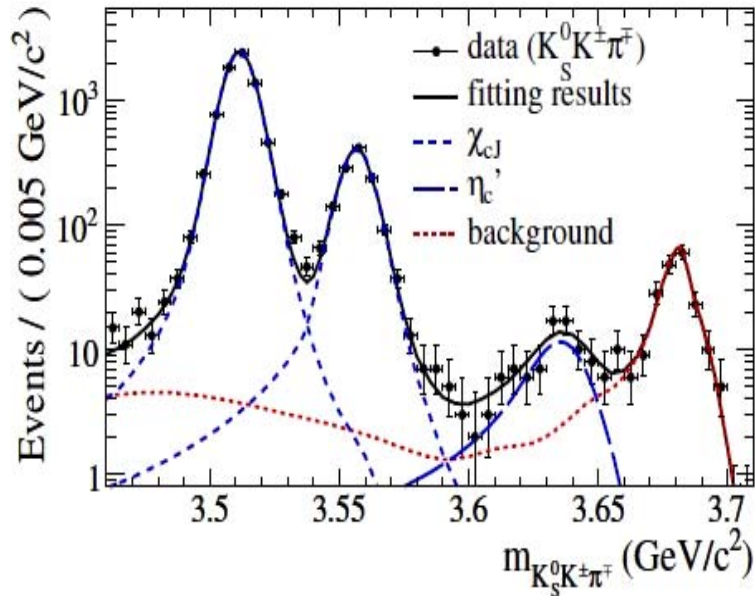


η_c'

- First “**observation**” by Crystal Ball in 1982 with $\psi' \rightarrow \gamma X$, but never confirmed by other experiments.
- Observed in different processes other than radiative transition
 - $B \rightarrow K \eta_c'$ *Belle: PRL89 102001 (2002)*
 - $\gamma\gamma \rightarrow \eta_c' \rightarrow KK\pi$ *CLEO-c: PRL92 142001 (2004)*
Belle: NPPS.184 220 (2008); PRL98 082001 (2007)
 - double charmonium production *BarBar: PRL92 142002 (2004); PRD72 031101 (2005)*
BarBar: PRD84 012004 (2011)
- The *M1* transition $\psi' \rightarrow \gamma \eta_c'$ has not been observed. (experimental challenge: search for photons with energy around 50 MeV)

Observation of $\psi' \rightarrow \gamma \eta_c'$

BESIII preliminary



- Simultaneous fit with:

- η_c' signal: modified BW (*M1*) (Resolution extrapolated from χ_{cJ})
- χ_{cJ} signal: MC shape smeared with Gaussian
- BG from $e^+ e^- \rightarrow KK\pi$ (ISR), $\psi' \rightarrow KK\pi$ (FSR), $\psi' \rightarrow \pi^0 KK\pi$: are measured from data

Statistical significance > 10 σ

Preliminary results on $\psi' \rightarrow \gamma \eta_c' \rightarrow \gamma \text{KK} \pi$

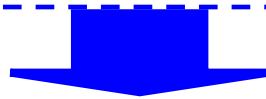
BESIII preliminary

- $M(\eta_c') = 3637.6 \pm 2.9 \pm 1.6 \text{ MeV}/c^2$

- $\Gamma(\eta_c') = 16.9 \pm 6.4 \pm 4.8 \text{ MeV}$

- $\text{Br}(\psi' \rightarrow \gamma \eta_c' \rightarrow \gamma \text{KK} \pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$

$\text{Br}(\eta_c' \rightarrow \text{KK} \pi) = (1.9 \pm 0.4 \pm 1.1)\%$ from BaBar



$$\text{Br}(\psi' \rightarrow \gamma \eta_c') = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$$

CLEO-c: $< 7.6 \times 10^{-4}$

(*PRD81,052002(2010)*)

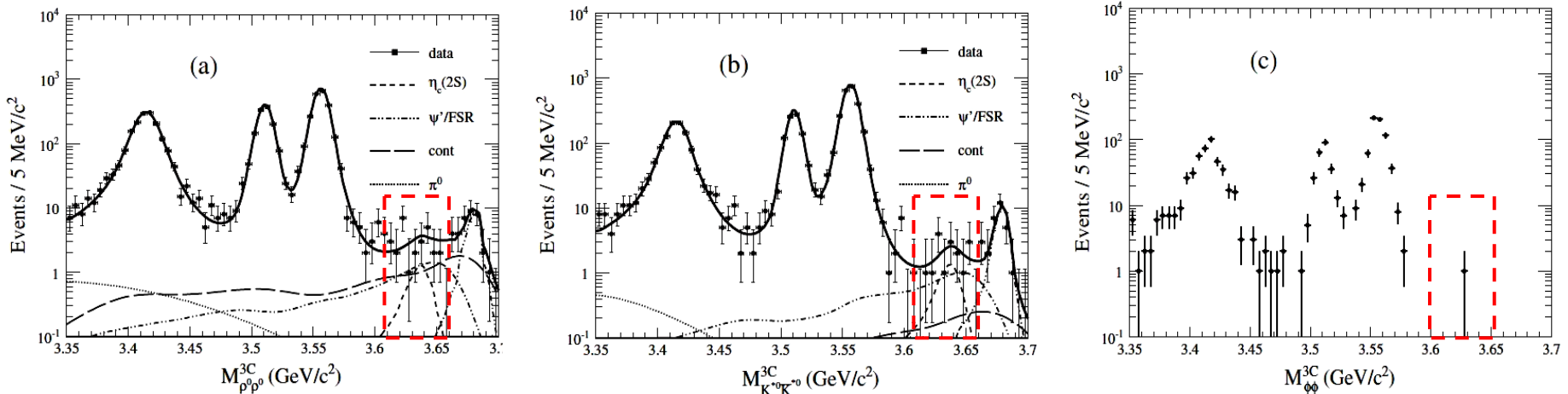
Potential model: $(0.1-6.2) \times 10^{-4}$

(*PRL89,162002(2002)*)

Search for $\eta_c' \rightarrow VV$ ($V=\rho, K^*, \phi$)

PRD84 091102 (2011)

Test for the “intermediate charmed meson loops” to evade helicity selection rule.



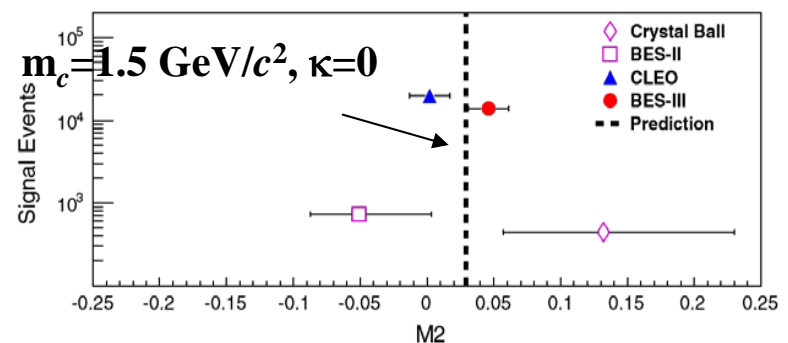
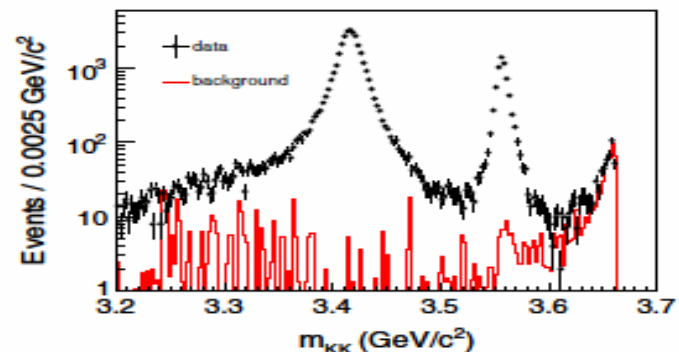
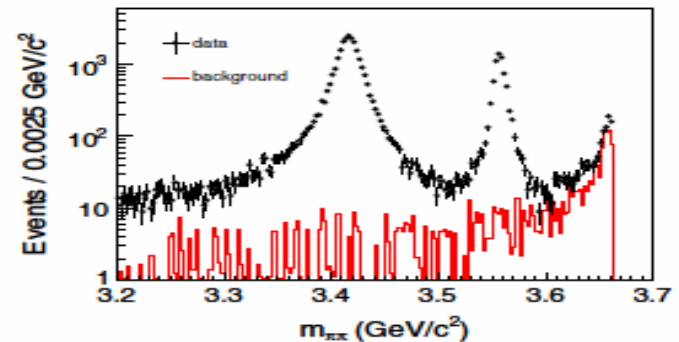
V	$B^{\text{up}}(\psi' \rightarrow \gamma \eta_c' \rightarrow \gamma VV)$ (10^{-7})	$B^{\text{up}}(\eta_c' \rightarrow VV)$ (10^{-3})	$B^{\text{theory}}(\eta_c' \rightarrow VV)$ (10^{-3})
ρ^0	12.7	3.1	6.4~28.9
K^{*0}	19.6	5.4	7.9~35.8
ϕ	7.8	2.0	2.1~9.8

No obvious η_c' signals in decays into vector pairs; the upper limit smaller than the lower bounds of theoretical predictions.

Higher multipoles in $\psi' \rightarrow \gamma \chi_{c2}$

PRD 84,092006(2011)

- $\psi' \rightarrow \gamma \chi_{c2}$ is dominated by electric dipole ($E1$) transition, but expect some magnetic quadrupole component ($M2$)
- $M2$ amplitude provides sensitivity to charm quark anomalous magnetic moment κ
 - Expect $M2 = 0.029(1 + \kappa)$
- Use large clean samples of $\chi_{c2} \rightarrow \pi\pi$ and $\chi_{c2} \rightarrow KK$; χ_{c0} samples used as control since $M2=0$
- Extract $M2$ using fit to full angular distribution
- Significant signal for $M2$ amplitude that is consistent with $\kappa=0$



Summary

- With the world largest ψ' data sample and the good performance of the BESIII detector, several interesting results came out:
 - The branching fractions of $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$ are determined, so the absolute η_c cross sections are available.
 - The **resonance parameters of η_c** have been measured in high precision; the **interference** between η_c and the non-resonant amplitudes around the η_c mass is considered for the first time.
 - **η_c'** was observed in ψ' decays for the first time, and decay modes other than $KK\pi$ are studied.
 - The transition amplitude of $\psi' \rightarrow \gamma \chi_{c2}$ maybe contain the contribution from high-order multipoles.
- BESIII now has ~ 3 times more ψ' , expect more results soon.

Thank you!