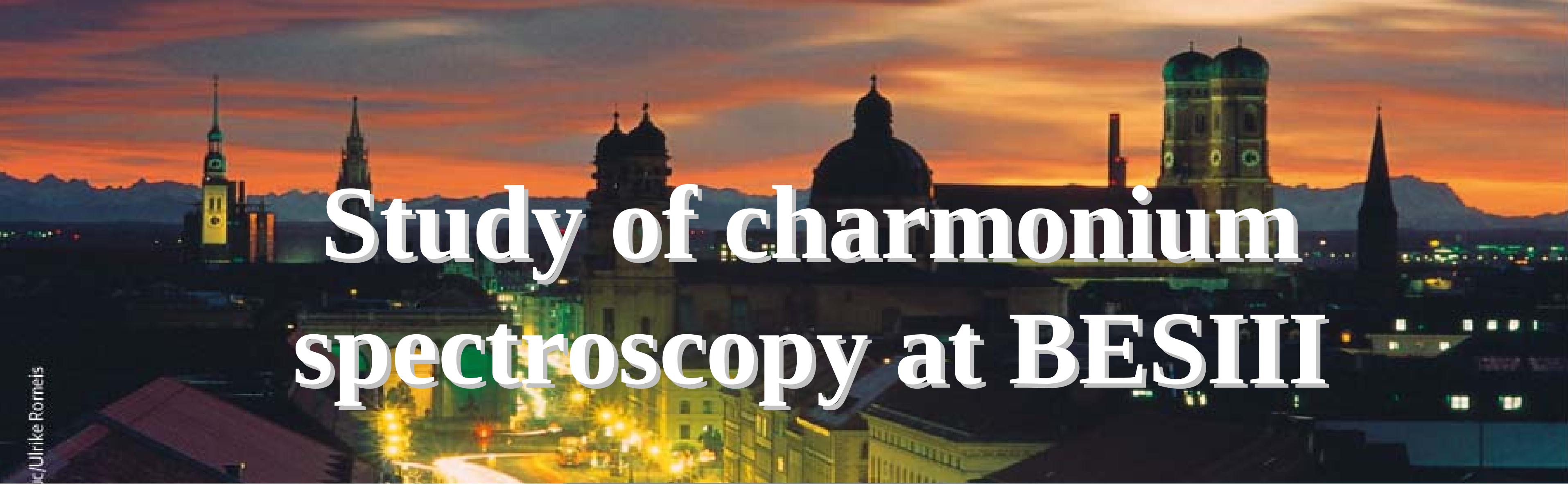

Study of charmonium spectroscopy at BESIII

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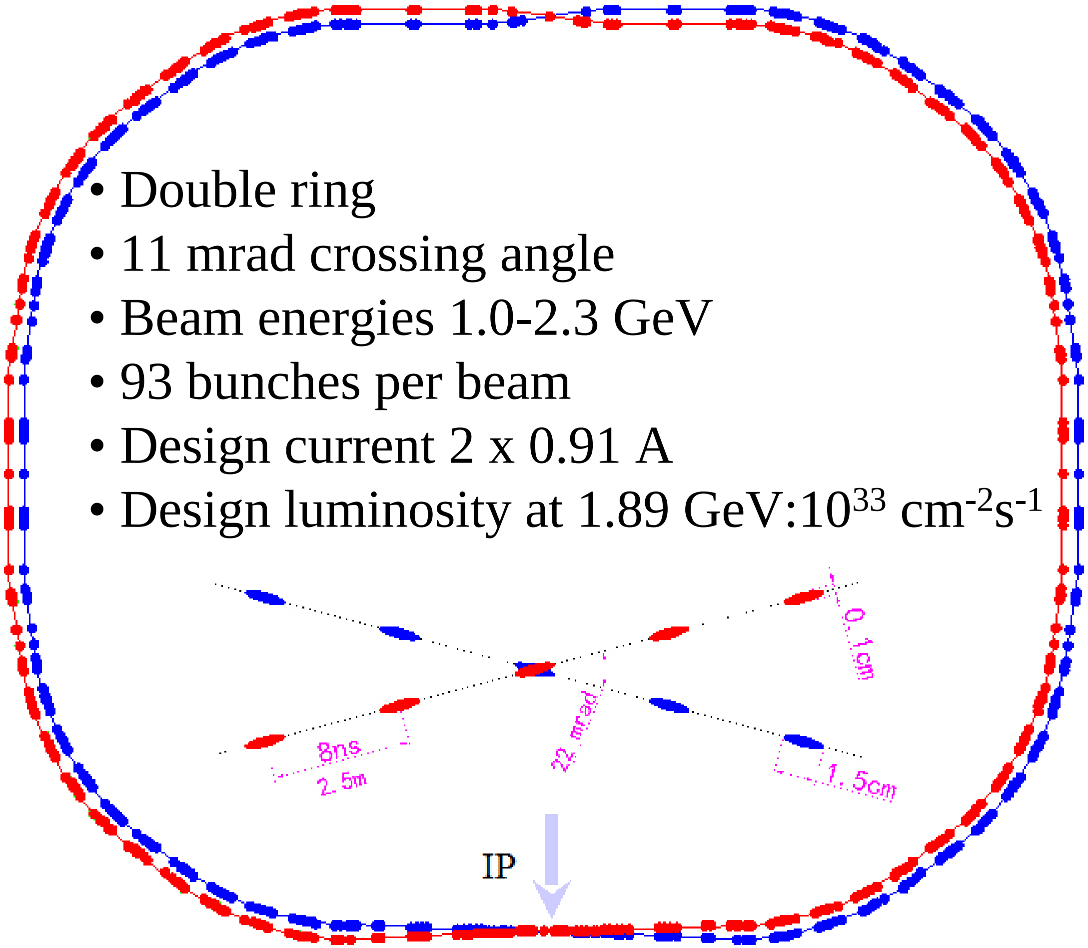
Hadron2011 München

Outline

- BEPCII and BESIII
- Observation of h_c at BESIII
- Precision measurement of the η_c properties at BESIII
- The first observation of the M1 transition $\psi' \rightarrow \gamma \eta_c(2S)$
- Summary

The Beijing Electron-Positron Collider II

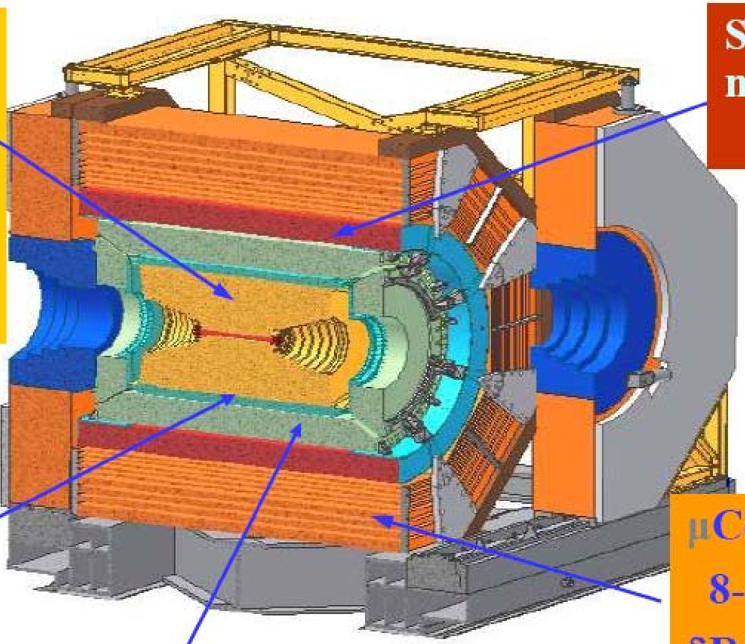
- Double ring
- 11 mrad crossing angle
- Beam energies 1.0-2.3 GeV
- 93 bunches per beam
- Design current 2 x 0.91 A
- Design luminosity at 1.89 GeV: 10^{33} $cm^{-2}s^{-1}$



The Beijing Spectrometer III (BESIII)

Main Drift Chamber (MDC)
$\sigma(p_T)/p_T = 0.32\% \oplus 0.37\%$ (1 GeV)
$\sigma_{dE/dx} = 5.3\%$

Super-conducting magnet
1.0 tesla



Time Of Flight (TOF)
σ_T = 80ps Barrel
100ps endcap

μCounter
8- 9 layers
$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\Delta E/\sqrt{E}$ = 2.5 % @ 1 GeV
$\sigma_{z,\phi}$= 0.6 cm /$\sqrt{E}$

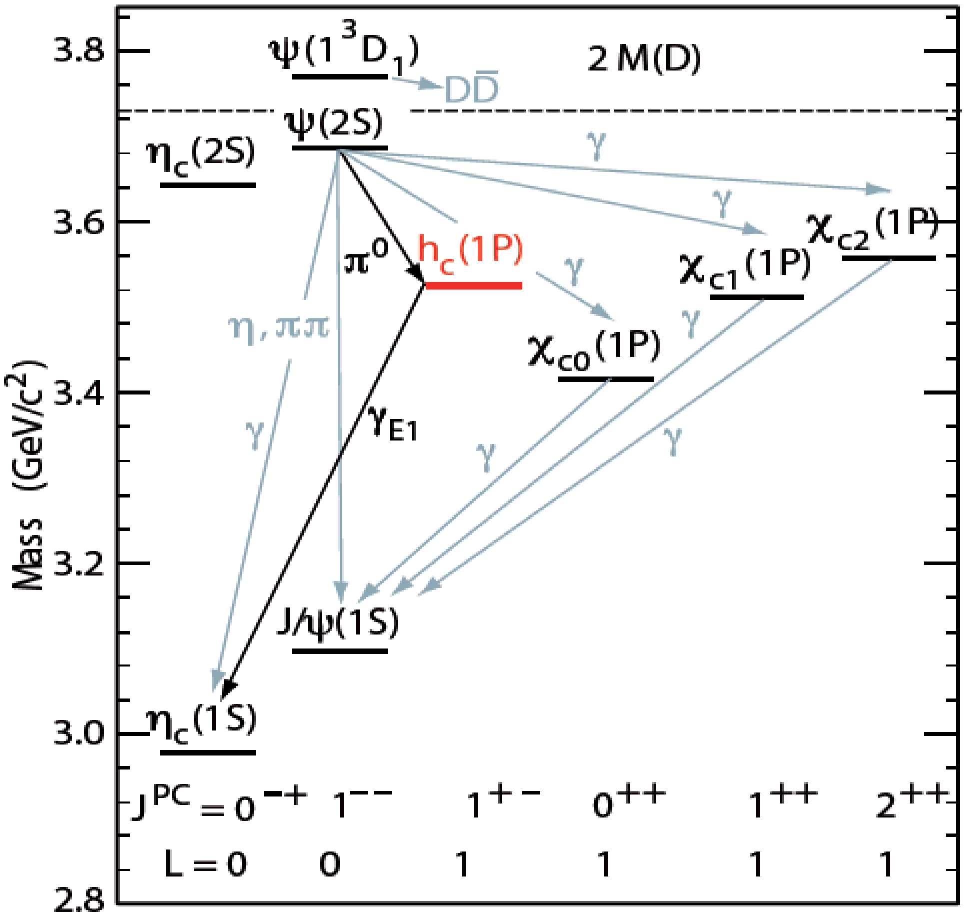
BESIII data samples

Energy points	luminosity	Number of resonant events
J/ψ	$65pb^{-1}$	226 million
ψ'	$150pb^{-1}$	106 million
3.65 GeV	$45pb^{-1}$	
$\psi(3770)$	$2900pb^{-1}$	
Scan around $\psi(3770)$ (3.646~3.892 GeV)	$76pb^{-1}$	
4.01 GeV ($\psi(4040)$)	$470pb^{-1}$	

Observation of h_c at BESIII

$h_c(^1P_1)$ in charmonium family

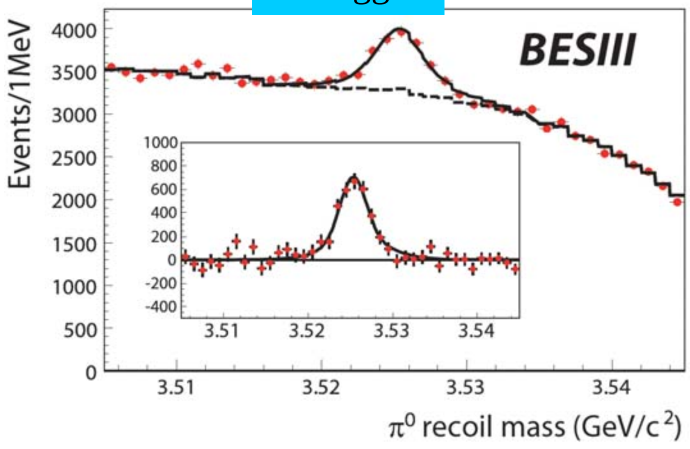
- Spin singlet P wave (S=0, L=1)
- Potential model if non-vanishing spin-spin interaction:
  $\Delta M_{hf}(1P)=M(h_c)-1/9(M(\chi_{c0})+3M(\chi_{c1})+5M(\chi_{c2}))\neq 0$
- E835 found evidence for h_c in $pp \to h_c \to \gamma\eta_c$
- CLEO-c observed h_c in $ee \to \psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$
  $\Delta M_{hf}(1P)=0.08\pm0.18\pm0.12 MeV/c^2$



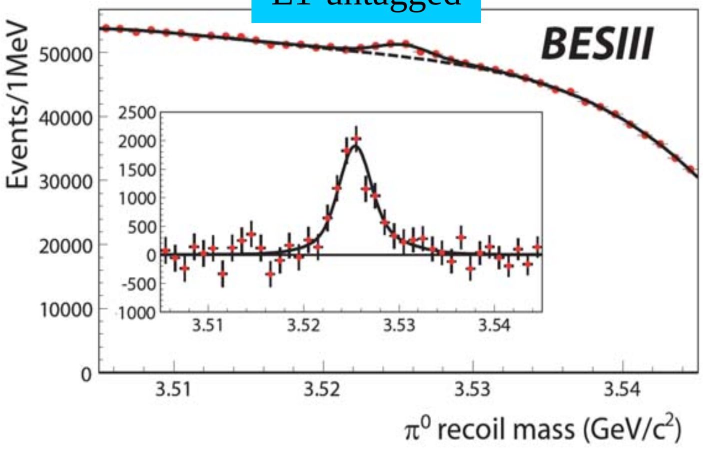
Observation of h_c at BESIII (inclusive)

BESIII Collaboration: PRL104, 132002, (2010)

E1-tagged



E1-untagged



- Select inclusive π^0 ($\psi' \rightarrow \pi^0 h_c$)
- Select E1-photon in $h_c \rightarrow \gamma \eta_c$ (E1 tagged) or not (E1 untagged)
- E1-tagged selection gives

  $M(h_c)$=3525.40±0.13 ±0.18MeV

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

  $\Gamma(h_c)$=0.73±0.45 ±0.28MeV

  (<1.44MeV at 90% CL)

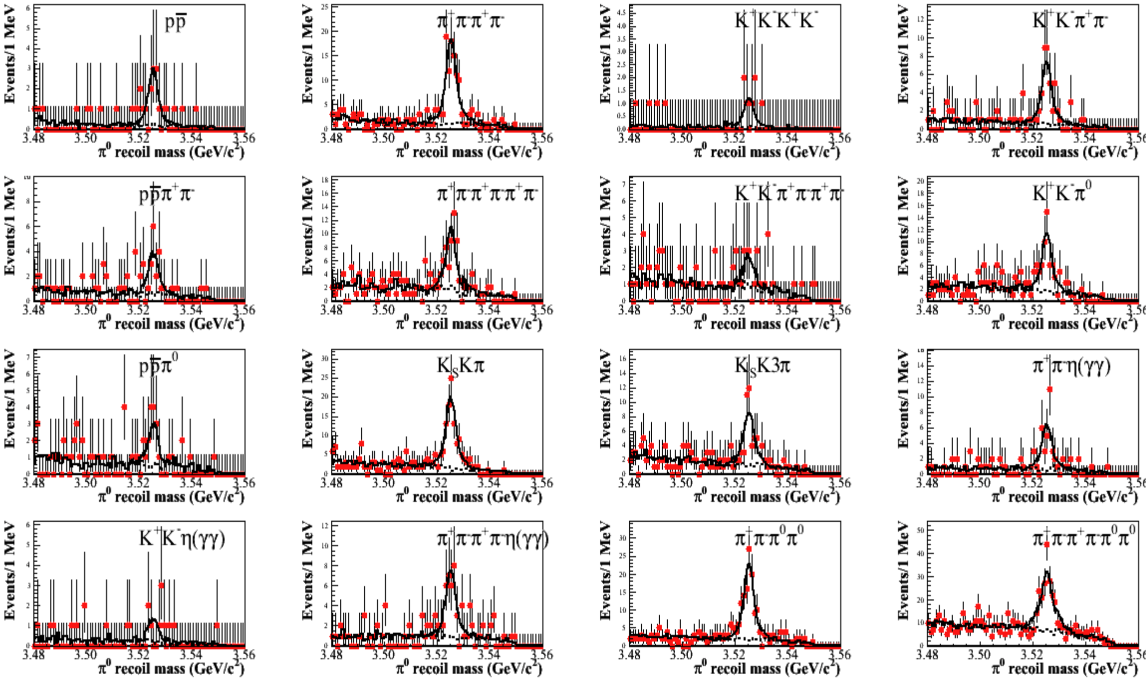
  $Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma \eta_c)$= (4.58±0.40±0.50) $\times 10^{-4}$

- E1-untagged together with tagged selection gives the first measurement

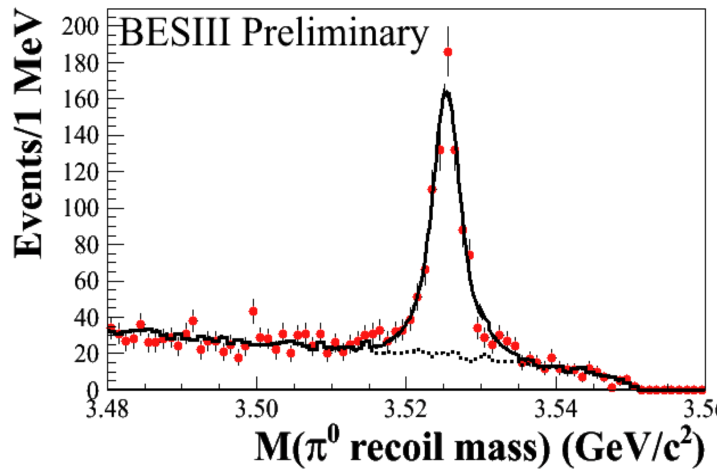
  $Br(\psi' \rightarrow \pi^0 h_c)$ =(8.4±1.3±1.0) $\times 10^{-4}$

  $Br(h_c \rightarrow \gamma \eta_c)$ =(54.3±6.7±5.2)%

Measurements of the h_c properties at BESIII (exclusive)



Summed π^0 recoil mass



Simultaneous fit to π^0 recoiling mass

$M(h_c)$ = 3525.31 ± 0.11 ± 0.15 MeV

$\Gamma(h_c)$ = 0.70 ± 0.28 ± 0.25 MeV

N = 832 ± 35

χ^2/d.o.f. = 32/46

BESIII preliminary

Consistent with BESIII inclusive results PRL104,132002(2010)

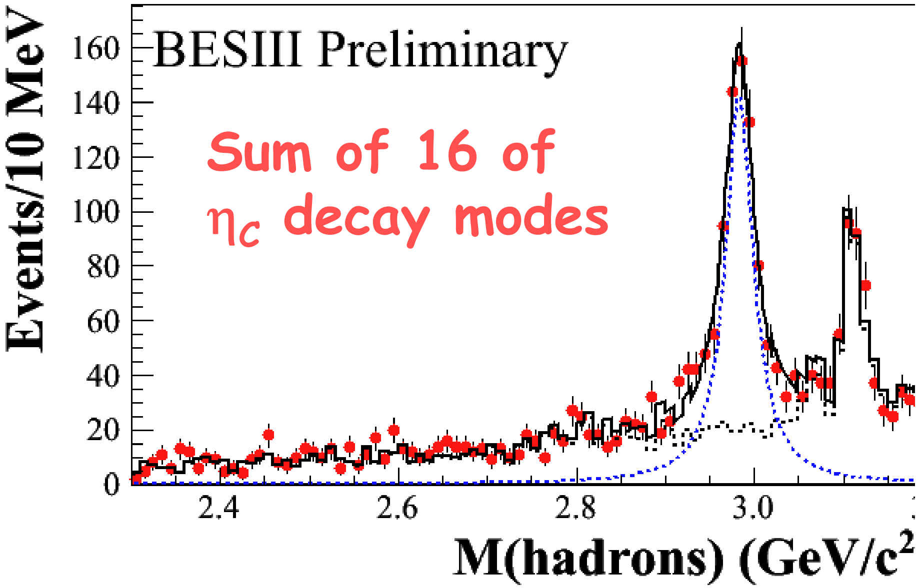
CLEOc exlusive results

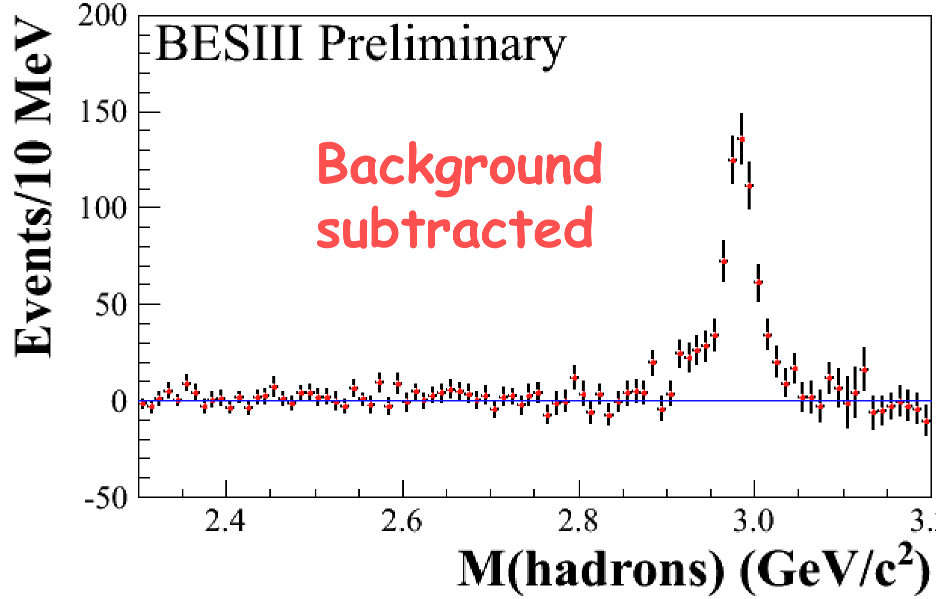
$M(h_c)$=3525.21±0.27±0.14 MeV/c^2

N = 136±14

PRL101, 182003(2008)

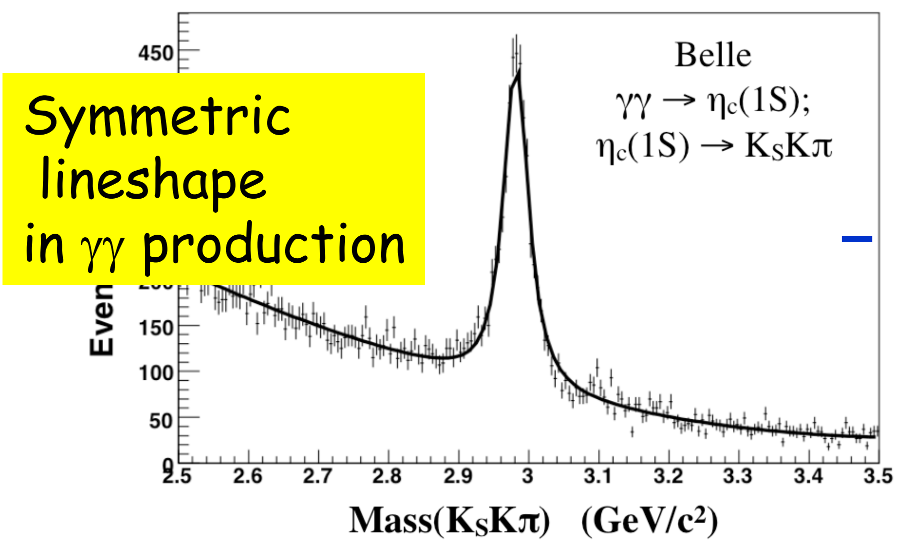
η_c lineshape from $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$

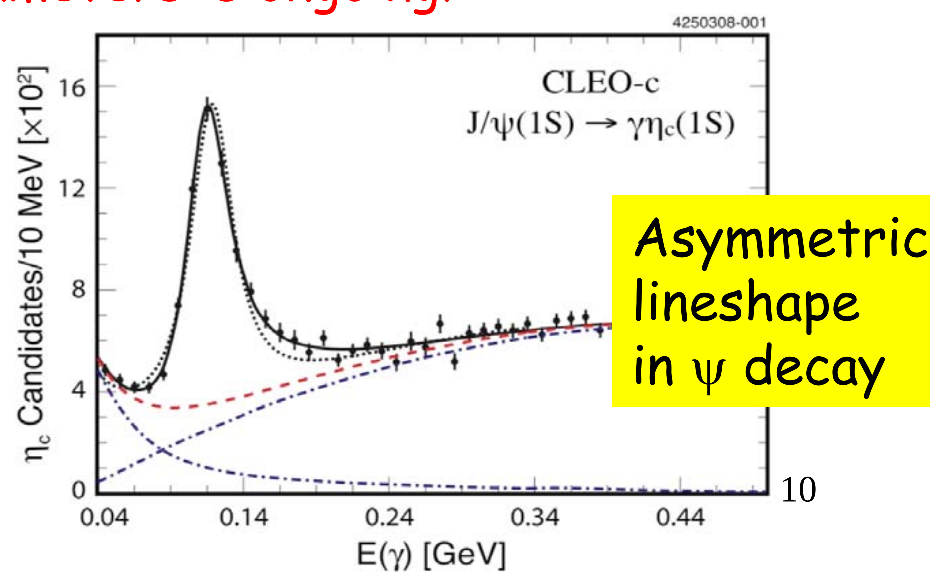




The η_c lineshape is not distorted in the $h_c \to \gamma\eta_c$

Detail analysis of η_c parameters is ongoing!





Precision measurement of the η_c properties

Introduction

- The lowest lying S-wave spin singlet charmonium η_c was discovered in 1980 by MarkII.
- Earlier experiments using J/ψ radiative transition gives $M(\eta_c)\sim2978.0 MeV/c^2$, $\Gamma(\eta_c)\sim10 MeV$.
- Recent studies using the two-photon processes gives $M(\eta_c)=2983.1\pm1.0$ MeV/c^2, $\Gamma(\eta_c)=31.3\pm1.9$ MeV.
- The most recent study from CLEO-c pointed out the distortion of the η_c line shape in ψ' decays.
- Measurement of the η_c properties at BESIII
  - Data sample: 106M ψ' events, 45pb^{-1} continuum data at 3.65 GeV
  - Decay modes X_i: KsKπ, $K^+K^-\pi^0$, $\eta\pi^+\pi^-$, KsK3π, $K^+K^-\pi^+\pi^-\pi^0$, $3(\pi^+\pi^-)$, where $Ks\to\pi^+\pi^-$, $\eta\to\gamma\gamma$, $\pi^0\to\gamma\gamma$

Backgrounds for $\psi' \rightarrow \gamma\eta_c \rightarrow \gamma X_i$

- $\psi' \rightarrow \pi^0 X_i$

  With the optimized selection, the mass spectra for $\pi^0 X_i$ events are measured in data and scaled according to the full simulation to estimate the contribution in $\gamma\eta_c$ candidates.

- Non-resonant contribution $\psi' \rightarrow \gamma X_i$

  exact the same final states, can not be removed

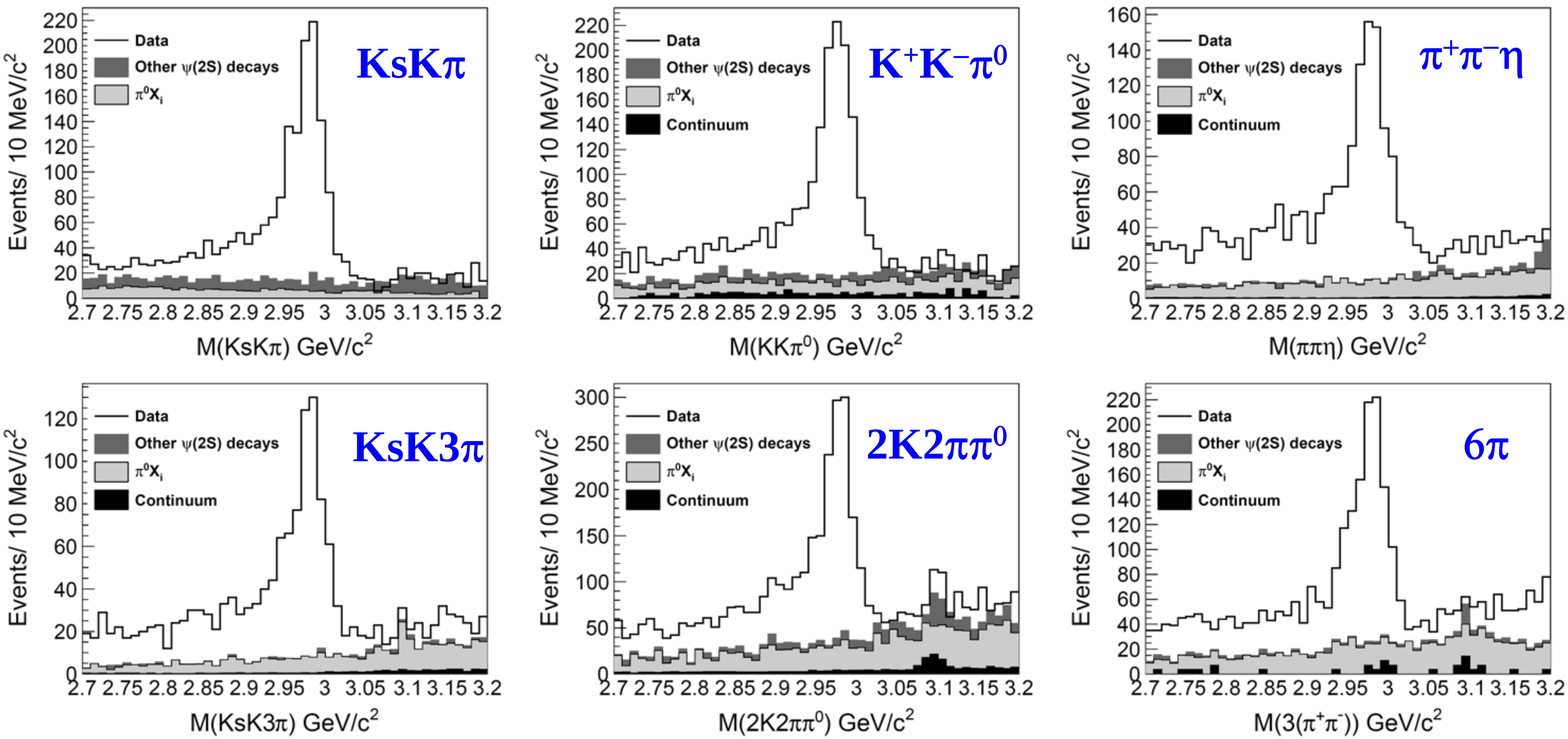
- Rare backgrounds

  Production rate or efficiency is very low, estimated based on the inclusive MC

- Continuum events

  Estimated by using the $45pb^{-1}$ data taken at 3.65GeV

Backgrounds for $\psi' \rightarrow \gamma\eta_c \rightarrow \gamma X_i$ (conti.)



Mass spectrum fitting

$$\sigma \bigotimes (\epsilon |e^{i\phi} f_1 \mathcal{S} + \alpha Non|^2 f_2) + BKG$$

- **S**: signal function (BW with mass width floated)
- **Non**: non-resonant γX_i PDF (all assumed to 0^{-+})
- **BKG**: the sum of other backgrounds $\pi^0 X_i$ + other rare ψ' decays + continuum, fixed in the fitting
- ϕ: interference phase between η_c decay and non-resonant contribution

Fit results for individual modes:

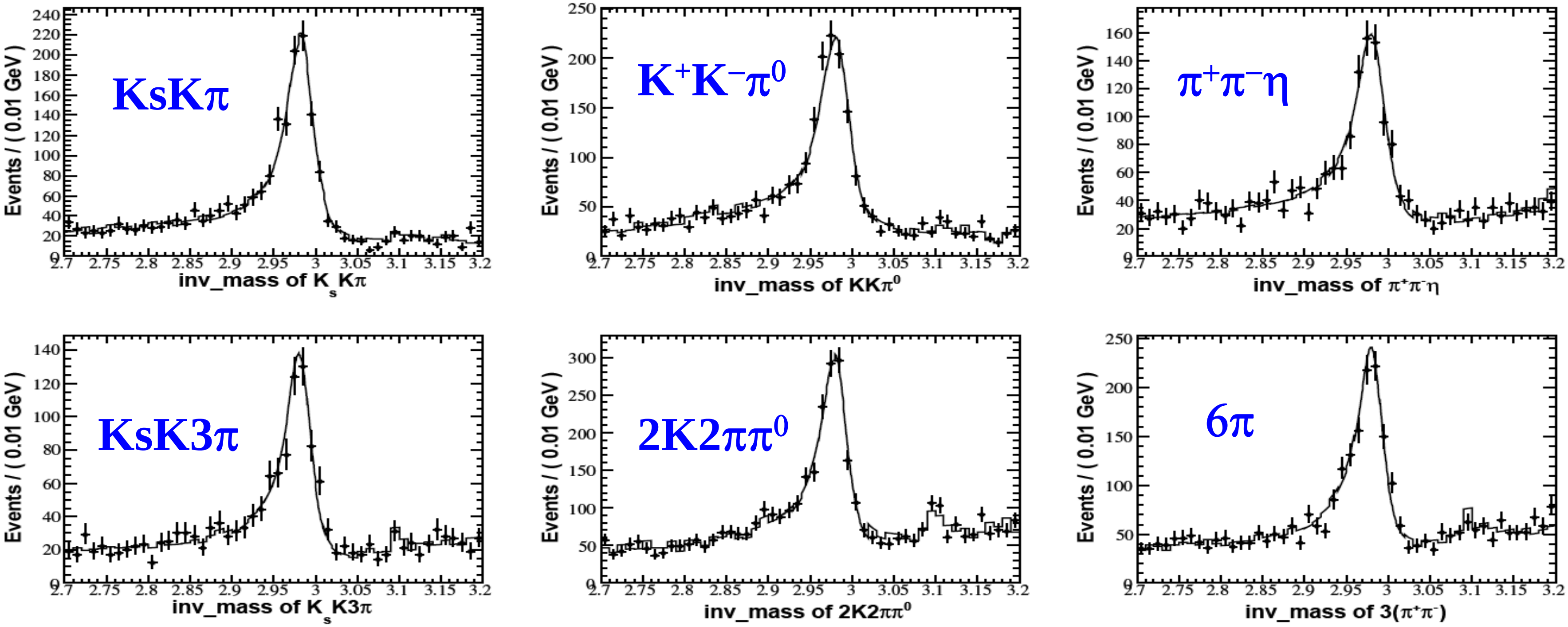
Interference

mode (i)	signal yield	ε (%)	mass (MeV/c^2)	width(MeV)	ϕ_i	$\chi^2/d.o.f$	significance
$K_S K^+ \pi^-$	880.4	35.0	2984.7 ± 1.2	32.5 ± 2.3	2.9 ± 0.3	1.1	6.4
$K^+ K^- \pi^0$	948.4	25.0	2980.3 ± 1.5	30.5 ± 2.4	2.4 ± 0.4	0.9	3.4
$\eta \pi^+ \pi^-$	573.4	25.0	2982.4 ± 1.8	31.0 ± 3.3	2.2 ± 0.2	1.2	3.8
$K_S K^+ \pi^+ \pi^- \pi^-$	432.3	11.0	2986.9 ± 2.1	34.1 ± 3.3	2.3 ± 0.2	0.7	4.4
$K^+ K^- \pi^+ \pi^- \pi^0$	1033.6	11.0	2985.4 ± 1.3	29.1 ± 2.8	2.6 ± 0.2	1.2	7.0
$3(\pi^+ \pi^-)$	664.4	17.0	2986.8 ± 1.3	33.7 ± 3.1	2.5 ± 0.1	1.1	7.0
combined	4532.5	-	2984.5 ± 0.6	31.7 ± 1.1	2.5 ± 0.1	-	-
C.L.	-	-	1.1%	89%	28%	-	-

Constant fitting gives χ^2/ndf=5.142/5

The simultaneous fit

The η_c mass, width and interference phase ϕ are constrained to be the same



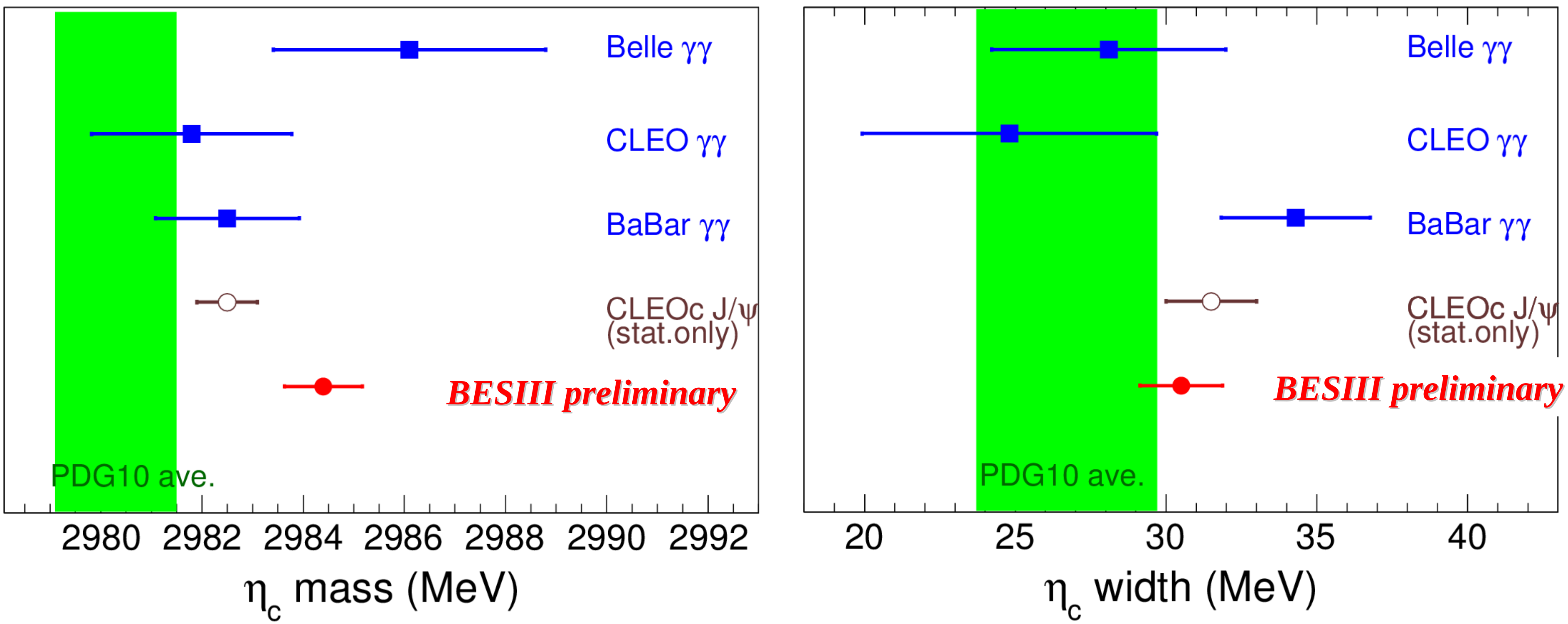
BESIII preliminary

- **mass = 2984.4 ± 0.5stat MeV/c²**
- **width = 30.5 ± 1.0stat MeV**
- **ϕ = 2.35 ± 0.05stat rad**

(the significance of the interference is 15σ)

Comparison of BESIII preliminary results with other measurements

PDG10 ave. : Earlier experiments using J/ψ radiative transition



The first observation of the M1 transition $\psi' \rightarrow \gamma \eta_c(2S)$

Introduction

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi' \to \gamma X$, never confirmed by other experiments.)

- Published results about $\eta_c(2S)$ observation:

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^\pm \to K^\pm \eta_c(2S), \eta_c(2S) \to K_S K^\pm \pi^\mp$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \to \eta_c(2S) \to K_S K^\pm \pi^\mp$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \to \eta_c(2S) \to K_S K^\pm \pi^\mp$
BaBar [4]	$3645.0 + 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \to J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12 \pm 3$ MeV

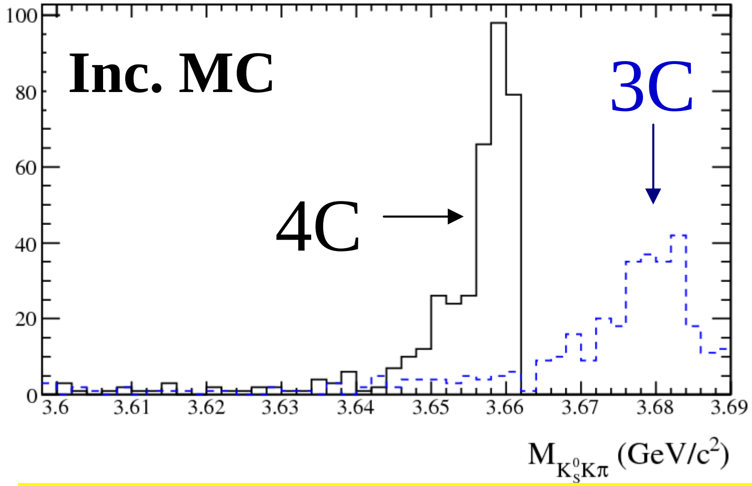
- The M1 transition $\psi' \to \gamma\eta_c(2S)$ has not been observed. (experimental challenge : search for real photons ~50MeV,)

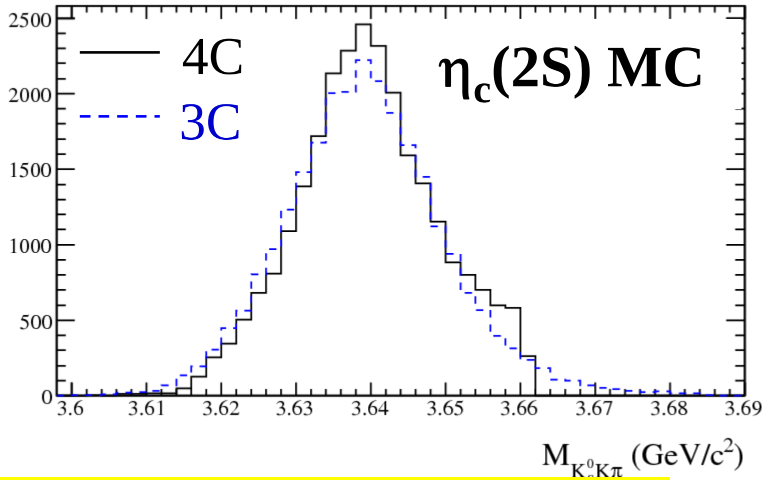
- Better chance to observe $\eta_c(2S)$ in ψ' radiative transition with ~106M ψ' data at BESIII.

- Decay mode studied: $\psi' \to \gamma\eta_c(2S) \to \gamma K_S K\pi$ ($K^+K^-\pi^0$ etc. in progress)

Mass spectrum representation

- The 4C kinematic fitting used to select the γKsKπ candidates (χ^2_{4C}<50)
- Still some KsKπ BG events contribute the γKsKπ candidates with a fake photon.
- The invariant mass from 4C-kinematic fits make the BG ψ'→KsKπ contaminates the η_c(2S) mass region (3.6~3.66GeV).
- The mass from 3C-kinematic fits (the measured energy of the photon is free) is little biased by the fake photon.
- Difference small between 4C and 3C for signal events





So the 3C fit mass used to determine the yields and parameters

Mass fitting

- $\eta_c(2S)$ signal:

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

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

E_γ^3 → M1 transition

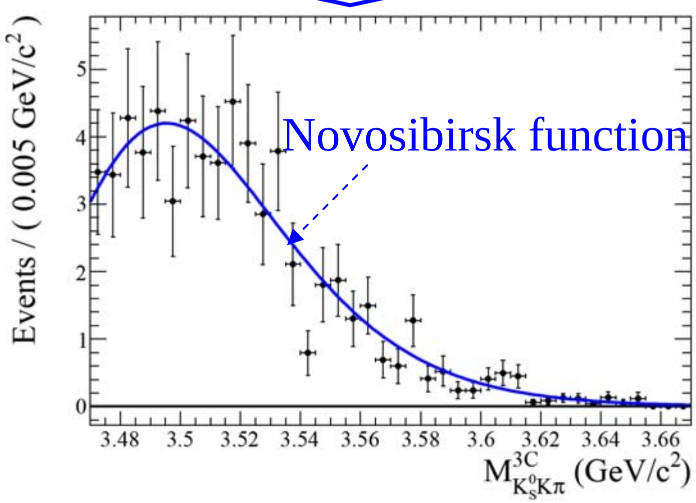
$damping(E_\gamma)$ → $\dfrac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$

σ → Fixed to the linear Extrapolation from $\sigma(\chi_{cJ})$

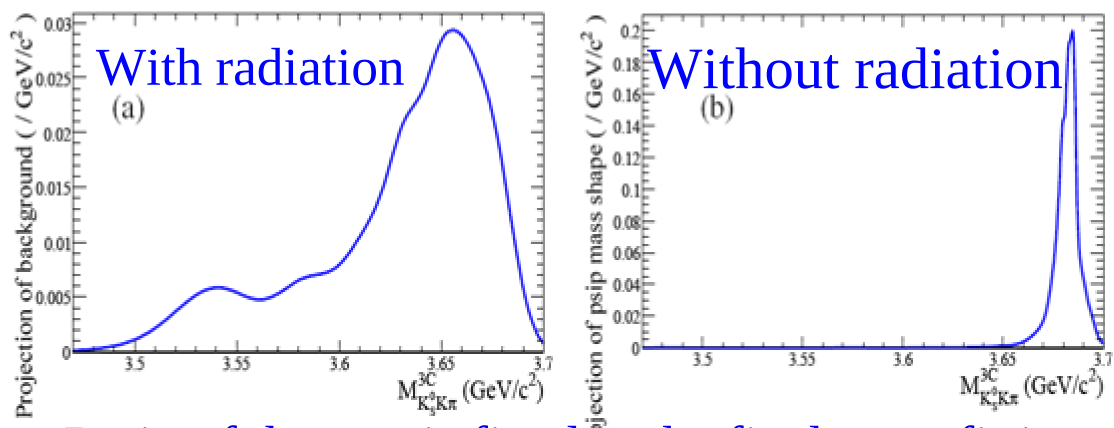
- χ_{cJ}: MC shape $\otimes$ a Gaussian

- BG from π^0KsKπ:

Measurement + scaling with MC simulation

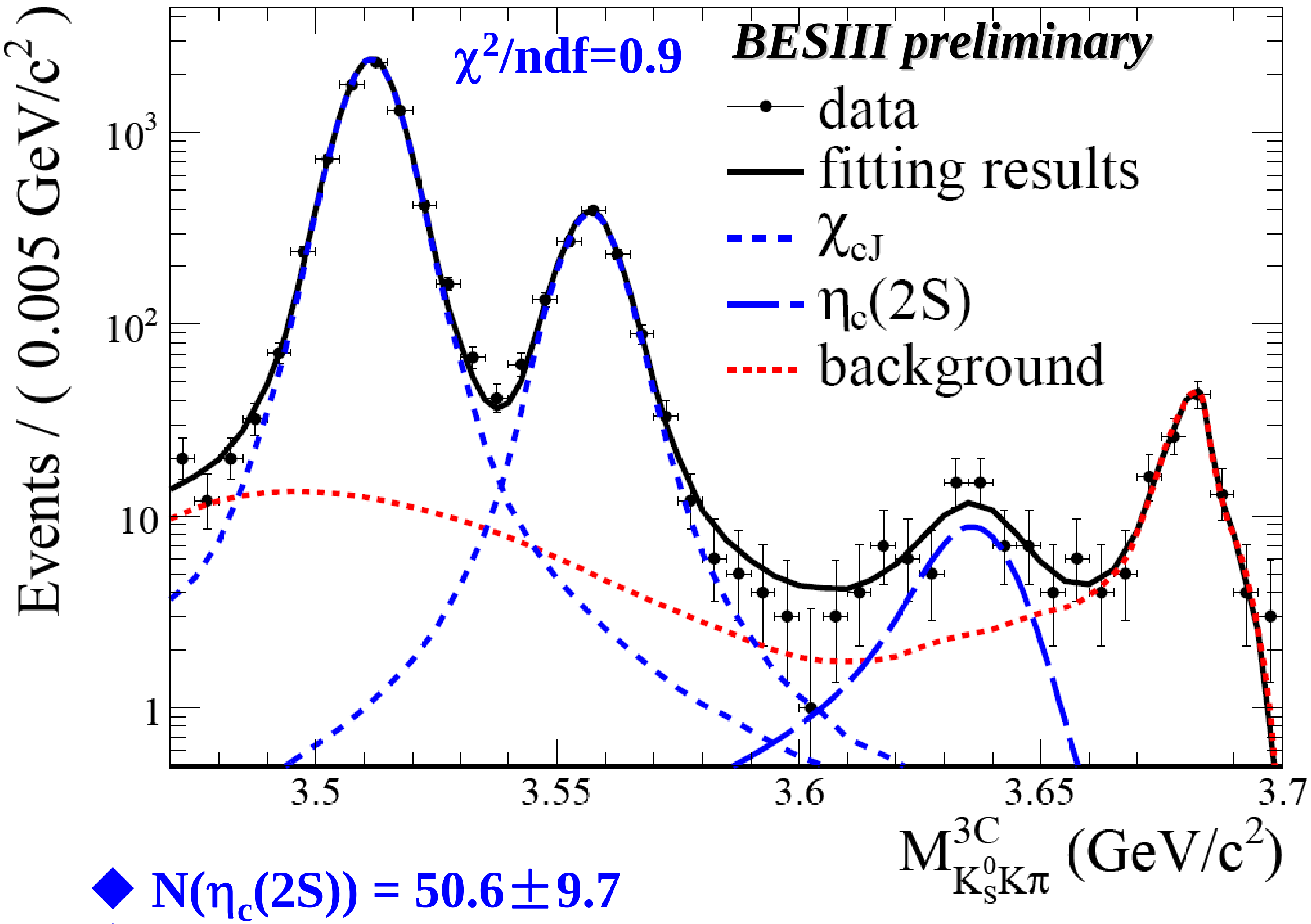


- BG from $\psi' \rightarrow$ KsK$\pi(\gamma_{FSR})$ & continuum (KsK$\pi(\gamma$ISR)):



Ratio of the two is fixed in the final mass fitting

Mass fitting (conti.)



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

Preliminary measurements from $\psi' \rightarrow \gamma\eta_c(2S) \rightarrow \gamma K_s K \pi$

- $M(\eta_c(2S)) = 3638.5 \pm 2.3_{stat} \pm 1.0_{sys}$ (MeV/c^2)
- $Br(\psi' \rightarrow \gamma\eta_c(2S) \rightarrow \gamma K_s K \pi) = (2.98 \pm 0.57_{stat} \pm 0.48_{sys}) \times 10^{-6}$

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

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

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

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

Summary

- High luminosity by BEPCII and the good performance of BESIII give us better chance to study the chamonium spectroscopy.
- Study of h_c at BESIII (inclusive & exclusive) gives the measurements of mass, width of h_c as well as $Br(\psi' \to \pi^0 h_c, h_c \to \gamma\eta_c)$.
- Precise measurement of the properties of η_c done at BESIII. The observed distortion η_c line shape described successfully by a interference model.
- The first observation of the M1 transition $\psi' \to \gamma\eta_c(2S)$.
- Great new studies will come out on the chamonium spectroscopy just from the largest $\psi(4040)$ sample already collected, but from much larger ψ' data next year at BESIII.

Thank you!

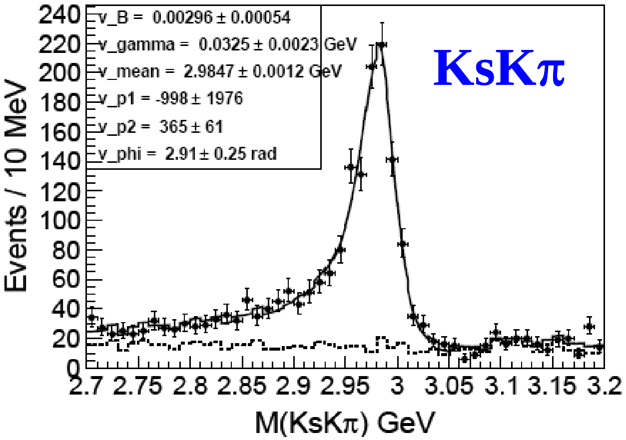
Backups

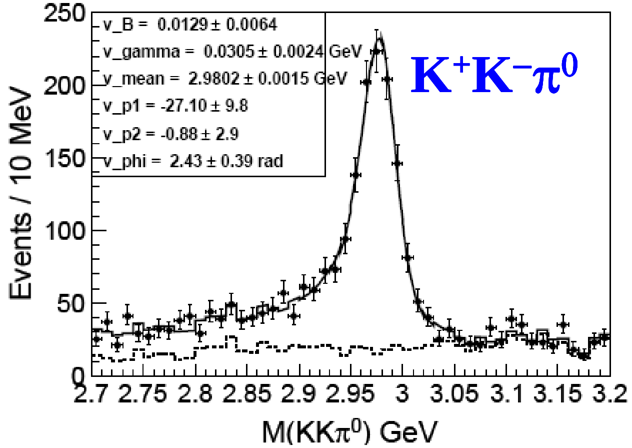
Fitting function

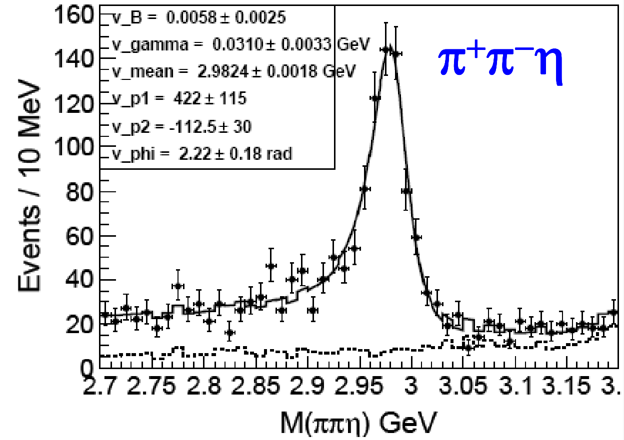
$$\sigma \bigotimes (\epsilon | e^{i\phi} f_1 \mathcal{S} + \alpha Non|^2 f_2) + BKG$$

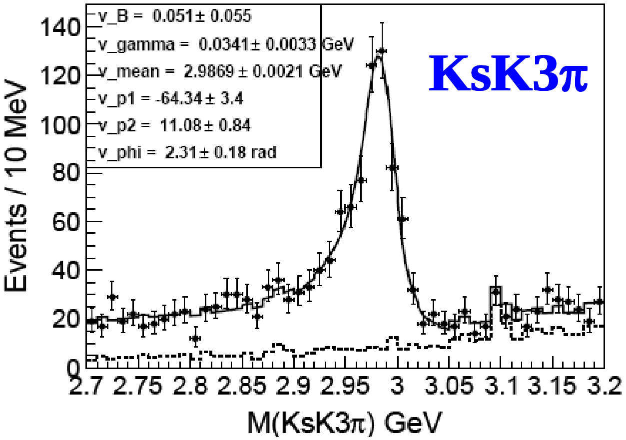
- **S**: signal function (BW with mass width floated)
- **Non**: non-resonant γX_i PDF (a 2nd-order Chebychev function with free parameters)
- **BKG**: the sum of other backgrounds $\pi^0 X_i$ + other rare ψ' decays + continuum, fixed in the fitting
- ϕ: interference phase
- α: the strength of the non-resonant
- ε: mass-dependent efficiency
- σ: experimental resolution
- $\mathbf{f_1^2 f_2}$: M1 form factor ($E_\gamma^4 E_\gamma^3 = E_\gamma^7$)

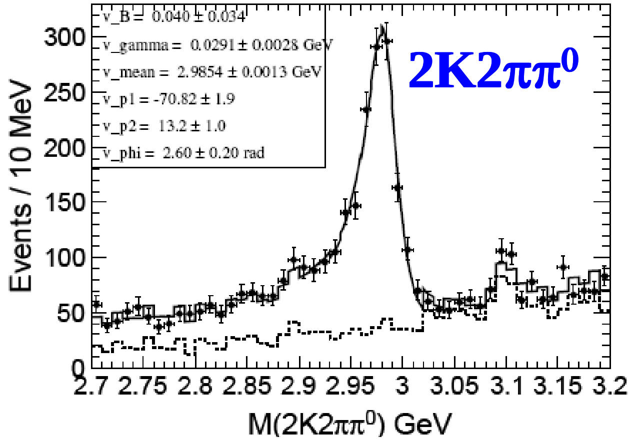
Results of the fits for different modes

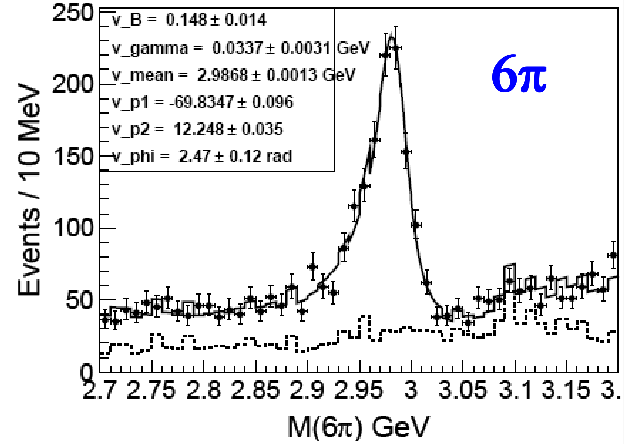












More consistency checks

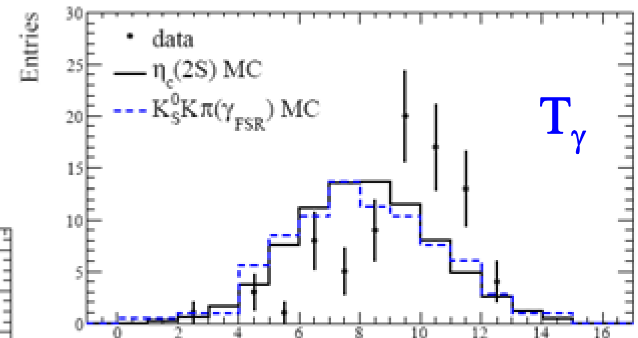
- Difference between the BG estimation and mass fitting ΔN=12±14
- Branching ratios for $\psi' \rightarrow \gamma\chi_{cJ} \rightarrow \gamma K_S K \pi$

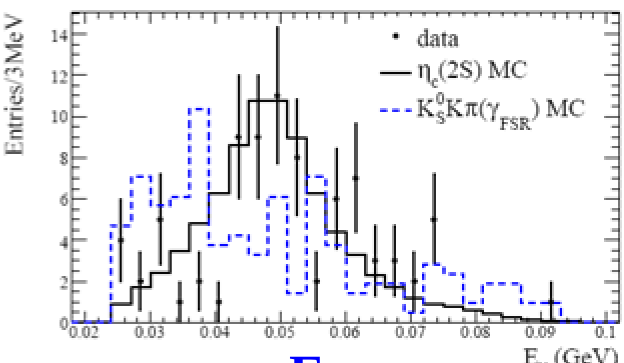
From this analysis (stat. err. only)

	N_{obs}	ϵ	$\mathcal{B}(\psi' \rightarrow \gamma\chi_{cJ}, \chi_{cJ} \rightarrow K^0_S K^{\pm}\pi^{\mp})$	$\mathcal{B}$ from PDG
χ_{c1}	7065 ± 88	27.2%	$(3.54 \pm 0.15) \times 10^{-4}$	$(3.39 \pm 0.34) \times 10^{-4}$
χ_{c2}	1204 ± 37	26.0%	$(6.31 \pm 0.30) \times 10^{-5}$	$(5.81 \pm 0.91) \times 10^{-5}$

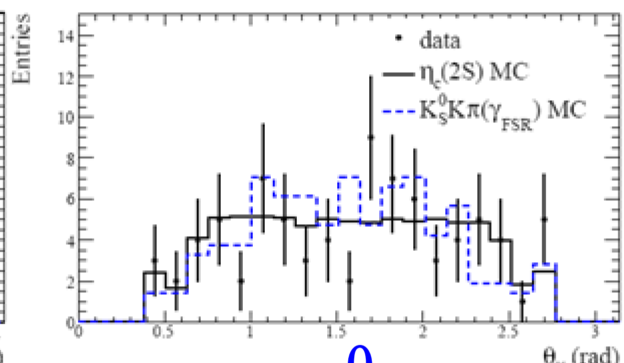
- The distributions of the selected photons

  $M_{K_S K\pi} \in (3.6, 3.66)$ GeV/c^2 :





E_γ



θ_γ