# Measurement of
$$\eta_c(1S, 2S)$$
in two-photon process
at Belle

H. Nakazawa (Belle Collaboration)

National Central University (R.O.C.)

July 9, 2007

Photon2007

Introduction
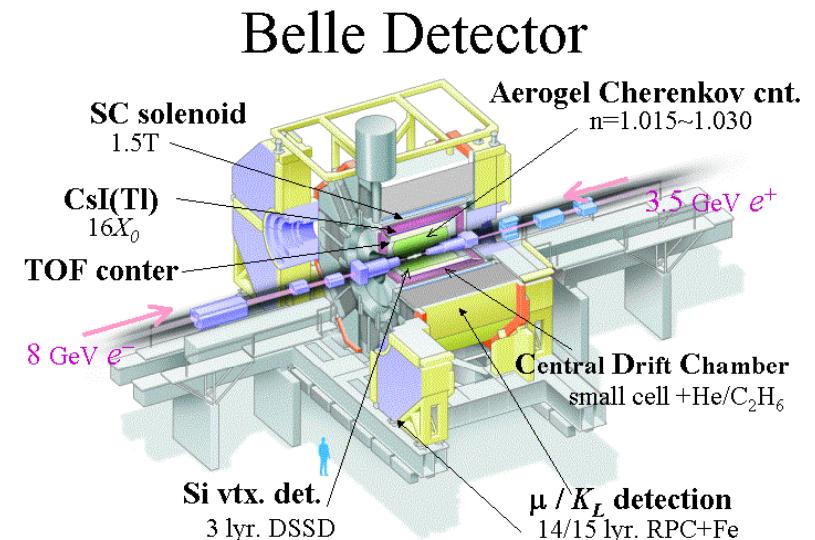
- $\eta_c^{(')}$ parameters give information on
    - How the spin influences a*r + b/r model
      by comparing J/Ψ parameters.
    - Test of various potential models that predict hyperfine splitting ratio between J/Ψ$^{(')}$ and $\eta_c^{(')}$ as well as two-photon decay width.
- $\eta_c^{(')}$ measurements have not been well established
  compared to J/Ψ$^{(')}$ since C=+1.
- Parameters measured have some range which may come from not only statistics but also analysis technique or interference effect.
- We use

$$ e^+e^- \rightarrow e^+e^- \ \gamma \ \gamma \rightarrow e^+e^- \ \eta_c^{(')} \rightarrow e^+e^- \ Ks \ K^{\pm} \ \pi^{\mp} $$

  mode.

Belle Experiment

- Coverage for this analysis

  33 deg < θ< 121 deg (TOF)

- Mass Resolution

  - ~2 MeV/c^2 for Ks

  - ~5-6 MeV/c^2 for KsKπ

- Kaon ID

  - Construct LR(likelihood ratio) from
    dE/dx, TOF, Cerenkov counter information

  - ~85% efficiency, ~10% fake rate for pion

- Data set

  - 483/fb collected with the Belle detector
    at KEKB collider by Aug. 2005.

Belle Detector

SC solenoid 1.5T

CsI(Tl) $16X_0$

TOF conter

8 GeV e^-

Si vtx. det. 3 lyr. DSSD

Aerogel Cherenkov cnt. n=1.015~1.030

3.5 GeV e^+

Central Drift Chamber small cell +He/C_2H_6

μ / K_L **detection** 14/15 lyr. RPC+Fe

Event Selection

Pre-Selection

$$\Sigma|p|<6\text{GeV/c}, \ \Sigma E<6\text{GeV}, \ \ MM^2>2(\text{GeV/c}^2)^2, \ \ \Sigma Q=0$$

N(track with pt>0.1GeV/c, |dr|<5cm, |dz|<5cm)=4

W(tracks with pt>0.3GeV/c, |dr|<1cm, |dz|<5cm)<4.5GeV/c^2

Ks selection

For each charged pion

•Pt > 0.1 GeV/c

•0.03cm<|dr| < 5cm

•|dz| < 5cm

For Ks candidates

•Best chi square

•Flight length in x-y plane > 0.08cm

•Azimuthal angle between 2 pion system and
        decay vertex < 0.1 rad

•Distance between 2 pions
        at the interception < 1.8 cm
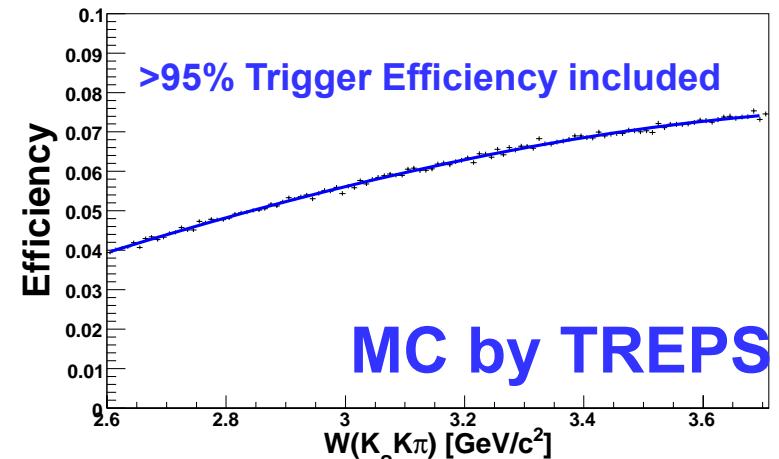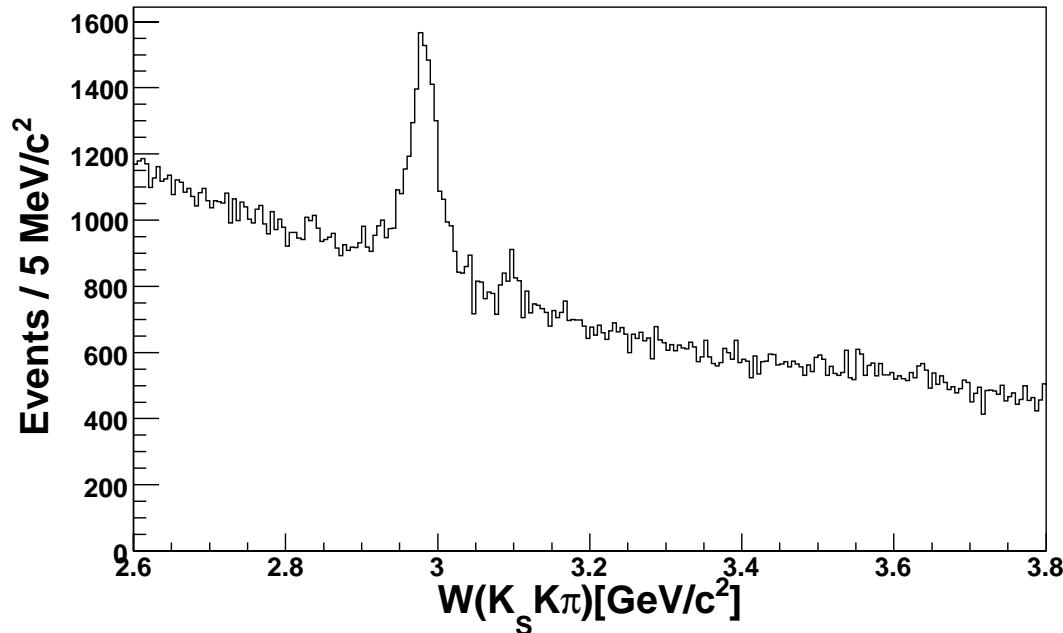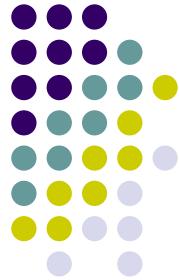
~75% reconstruction efficiency

Ks mass is constrained to the world average
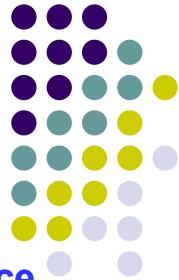
Charged K, π selection

•Pt >0.4 GeV/c

•|dr| < 1cm

•|dz| < 5cm

•|dz$^+$-dz$^-$|<1cm

•LR(K, π)>0.8 for K

•LR(K, π)<0.5 for π

Invariant mass distribution
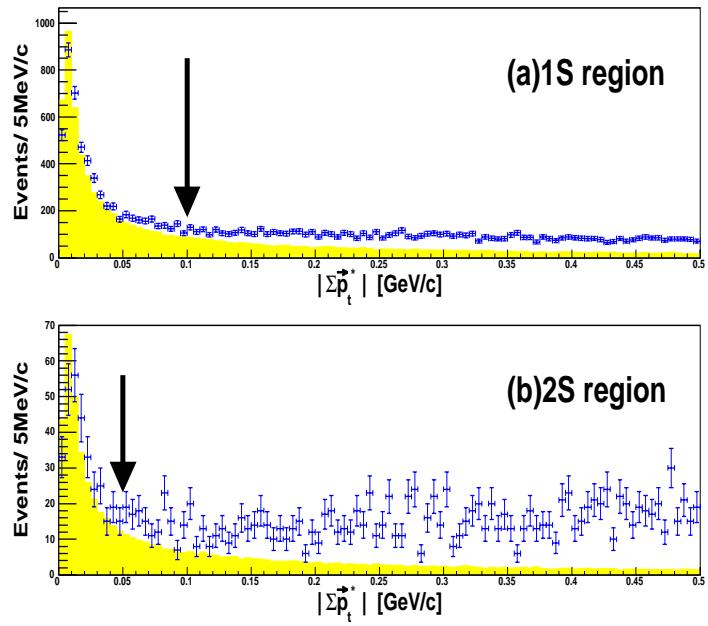
- Clear $\eta_c(1S)$ with small J/ψ peak seen.
- $\eta_c(2S)$ peak is buried in Background.
- Efficiency 4-7% in this region.
- Trigger Efficiency 95-97% by simulator
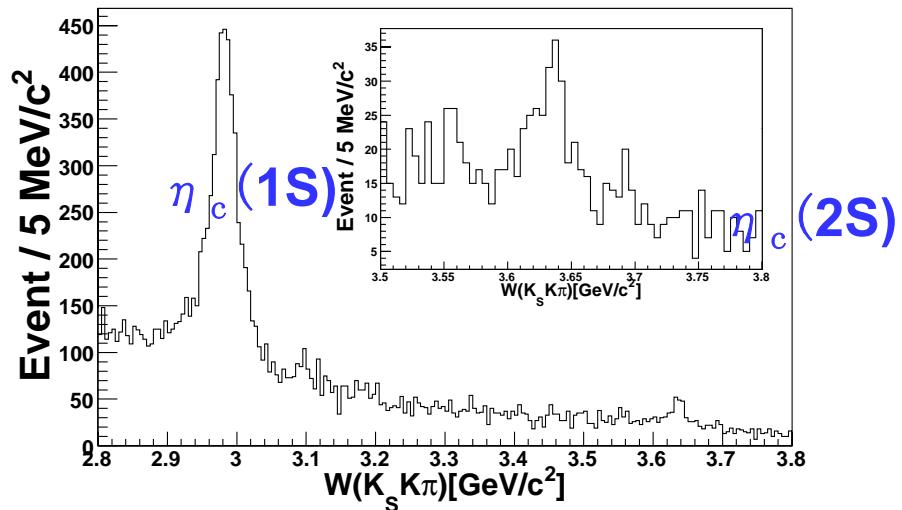
Pt-balance Cut

- **Definition:** $\left| \Sigma \vec{p}_t{}^* \right|$
- **Collect events from quasi-real two photon process by tight cut**

- **Clear Signal Peaks seen in pt-balance.**
- **Signal MC is normalized to <30MeV/c.**
- **Small bg fraction in $\eta_c(1S)$ region.**
- **Large bg fraction in $\eta_c(2S)$ region.**
- **<0.1 GeV/c for $\eta_c(1S)$**
- **<0.05 GeV/c for $\eta_c(2S)$**

The peaks are fitted to 2 models where
(1) No interference
(2) Continuum coherently interferes with the peak
(assuming all continuum has 0⁻ state)
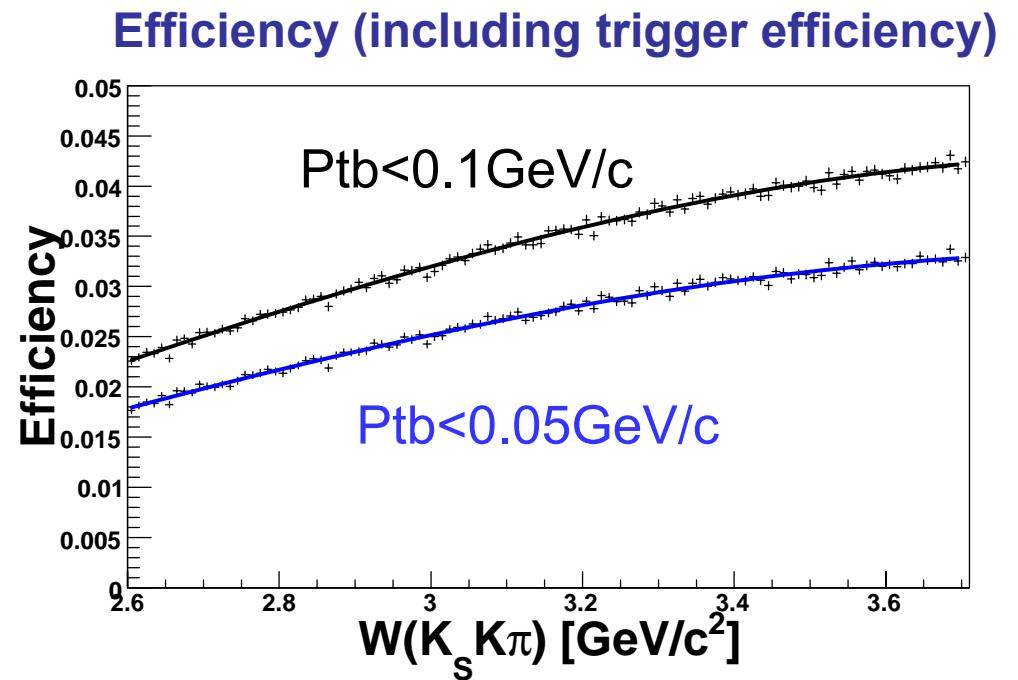
Fit   Parameters (no interference)

$$\frac{N \cdot dW \cdot \Gamma / 2\pi}{(W - M)^2 + (\Gamma / 2)^2} \otimes Gauss(\sigma) \times effi(W) + cont(W)$$

- **Binned chi square fit**
- **Fit with gaussian convoluted Breit-Wigner**
- **Efficiency term effi(W): 3rd order Polynomial**
- **Continuum term cont(W): 2nd order Polynomial**

Efficiency (including trigger efficiency)

N	Number of peak events (Efficiency corrected)
dW	Bin Width
Γ	Width
M	Mass
σ	Mass resolution from MC
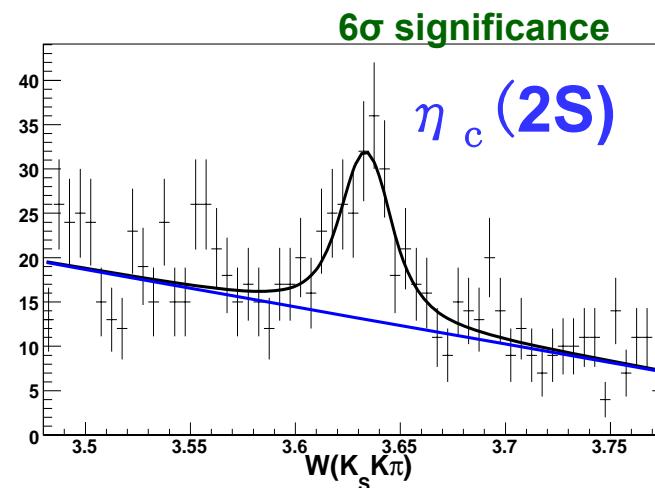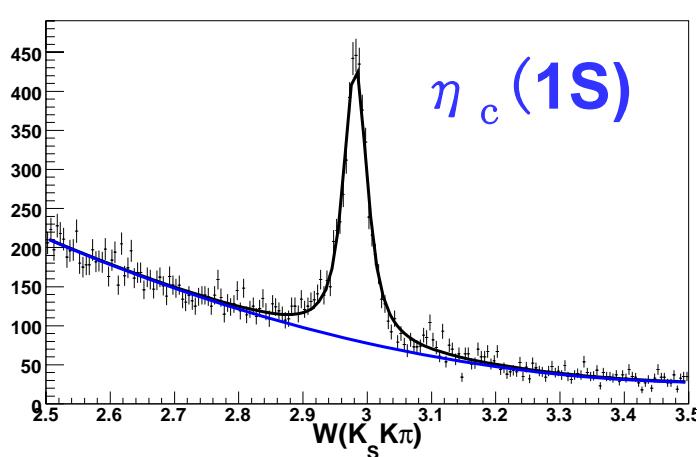
Fit Results and Extraction of Two-photon Decay Width

$$\Gamma_{\gamma\gamma}(\eta_c) = \frac{M_{\eta_c}^2 \mathcal{N}}{4\pi^2(2J+1)\mathcal{L}_{\gamma\gamma}(M_{\eta_c})\mathcal{B}(\eta_c \to K_S K^{\pm}\pi^{\mp})\int \mathcal{L}dt}$$

|	$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
$\eta_c(1S)$	7.48 ± 0.20	142.1 ± 3.8	144266 ± 3843	36.6 ± 1.5	2981.4 ± 0.5	5.15
$\eta_c(2S)$	0.59 ± 0.13	11.2 ± 2.4	4626 ± 989	19.1 ± 6.9	3633.7 ± 2.3	6.49

B(η_c(2S) →KsKπ) is assumed to be equal to B(η_c(1S) →KsKπ)
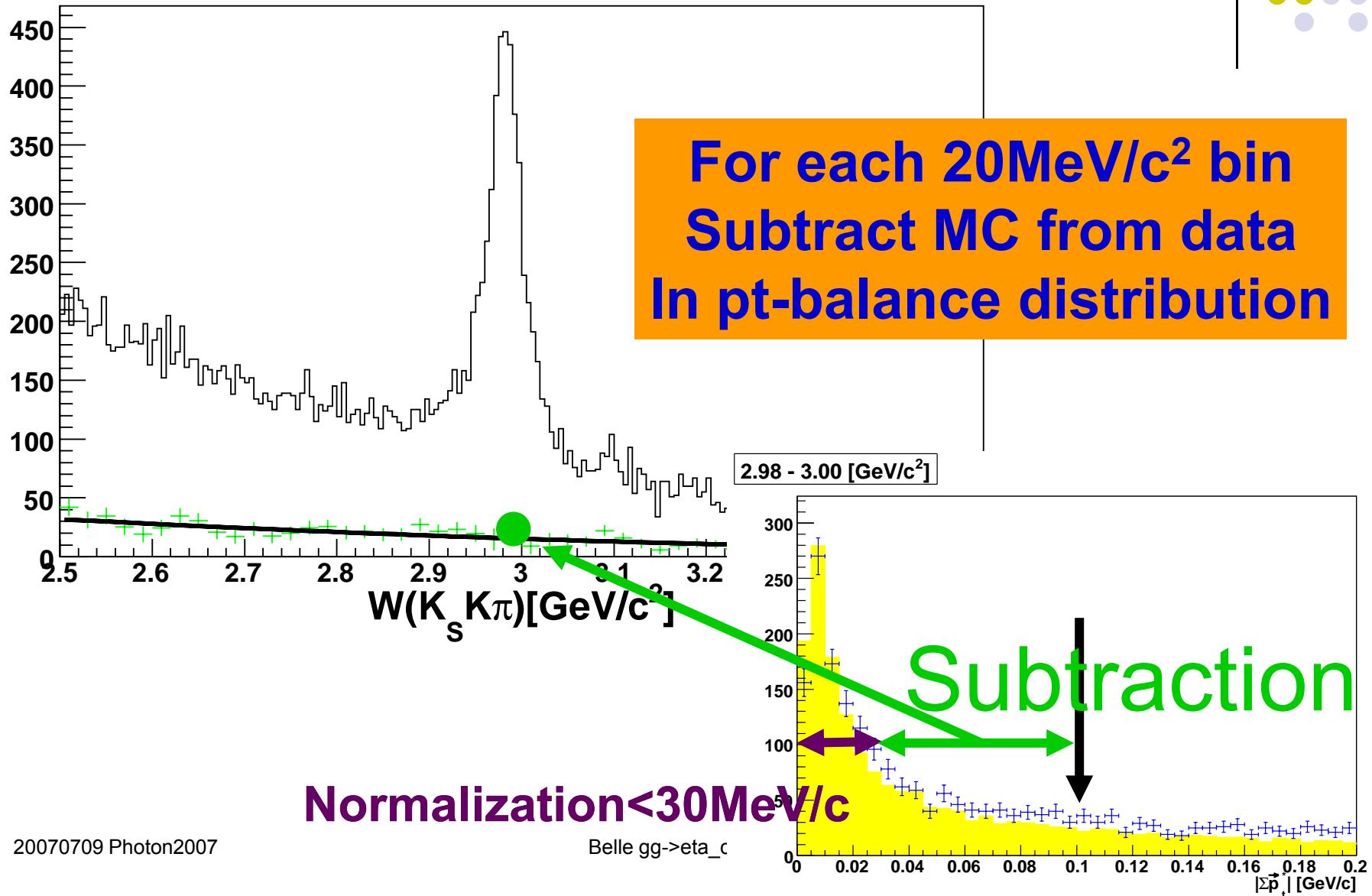
Systematic Errors (%)
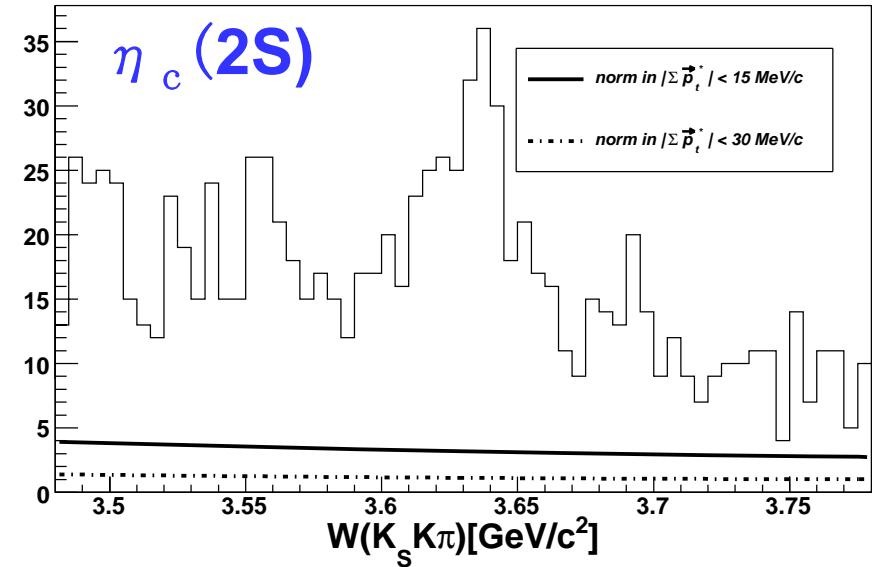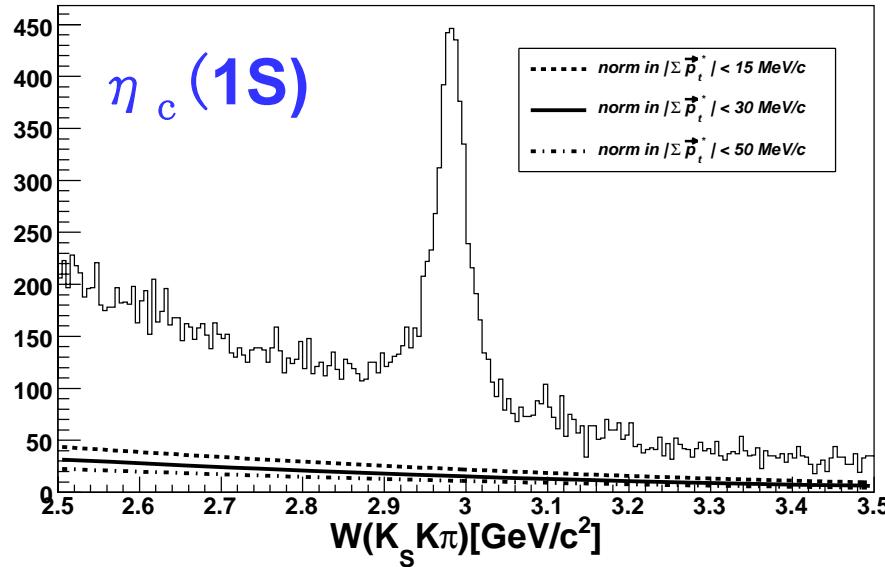
	$\Gamma_{\gamma\gamma}$		M		Γ	
	1S	2S	1S	2S	1S	2S
Ks ID	1					
Luminosity function	5					
Integrated Luminosity	1					
Trigger Efficiency	4					
Fit Range	0.1	3	---	0.01	0.1	3
Continuum function	4.0	17	0.01	0.01	4.8	21
J/psi	0.3		---		---	
MC Mass shift	---	---	0.01	---	---	---
Pt-balance cut	1.8	14	0.01	0.05	0.4	18
Mass resolution	0.6	2	---	---	2.4	7
Total	7.9	23	0.01	0.05	5.5	29

Background estimation using pt-balance

For each 20MeV/c² bin
Subtract MC from data
In pt-balance distribution

2.98 - 3.00 [GeV/c²]

Subtraction

Normalization<30MeV/c

Belle gg->eta_c

Variation of Background

- Data and MC Pt-balances ~0GeV/c not match well.
- Pt-balance<15, <30, <50MeV/c normalizations are tried.
- Background magnitudes differ by factor 2-3.

Fit Parameters for fit with interference
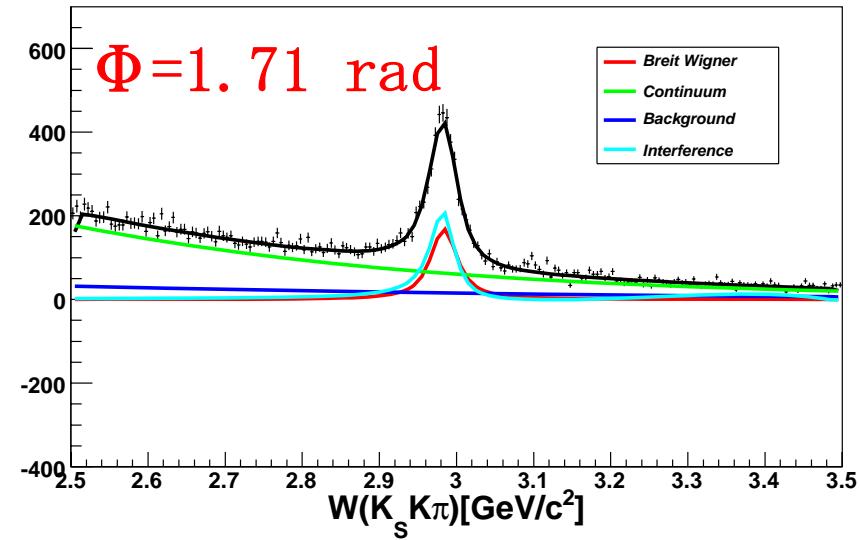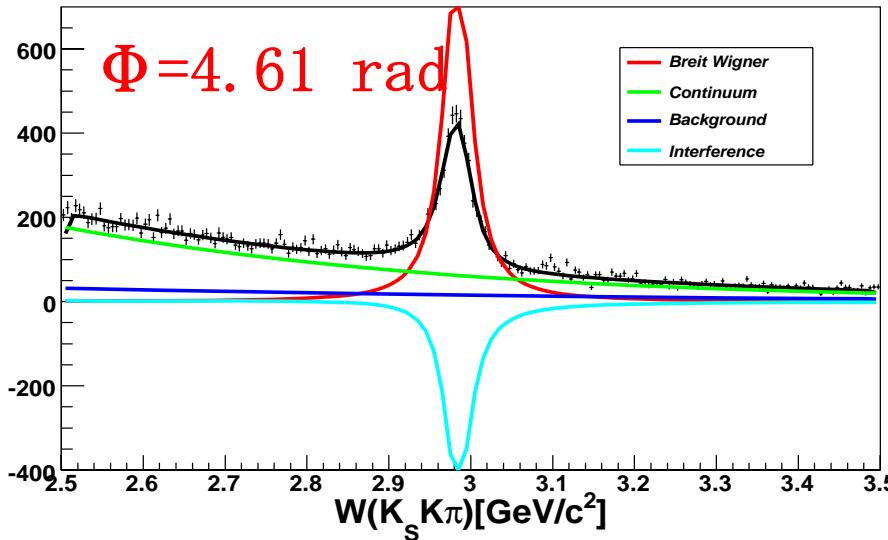
$$\left| \frac{\sqrt{N \cdot dW \cdot \Gamma / 2\pi}}{W - M - i\Gamma / 2} + e^{i\phi} \sqrt{c_0 (W - c_1)^{c_2}} \right|^2 \otimes Gauss(\sigma) \times effi(W) + bkg(W)$$

N	Number of peak events
dW	Bin Width
Γ	Width
M	Mass
Φ	Phase
c_i	Continuum params
σ	Mass resolution

- Assumed all fraction of the continuum interferes with the peak
- Efficiency term effi(W):
  3rd order polynomial
- Background term bkg(W):
  2nd order polynomial

Fit η$_c$(1S) Peak

Φ=4.61 rad

Breit Wigner	
Continuum	
Background	
Interference	

W($K_S K\pi$)[GeV/c^2]

Φ=1.71 rad

Breit Wigner	
Continuum	
Background	
Interference	

W($K_S K\pi$)[GeV/c^2]
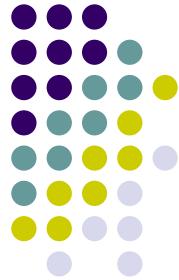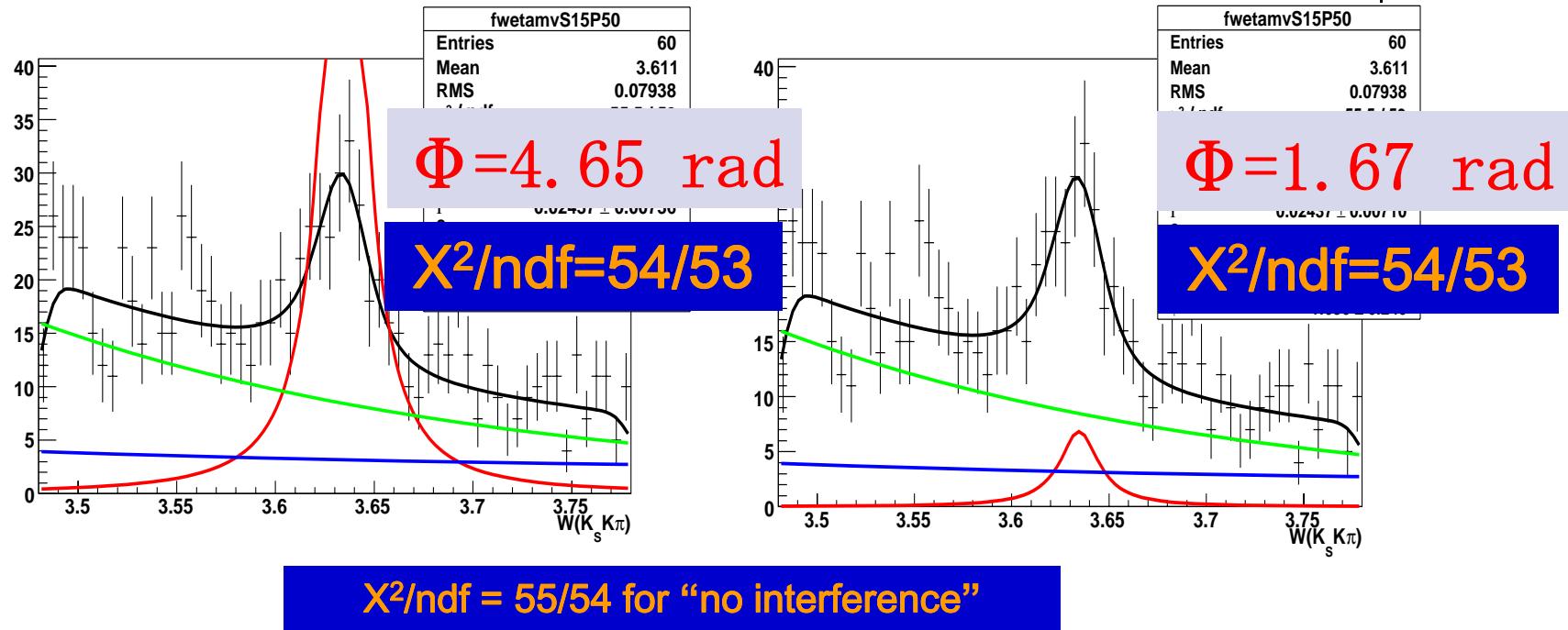
X^2/ndf=256/193

X^2/ndf=256/193

X^2/ndf = 248/194 for "no interference"

$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	ϕ [rad]	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
16.53 ± 0.41	314.0 ± 7.7	318315 ± 7676	4.61 ± 0.02	37.2 ± 1.4	2983.6 ± 0.7	5.2
1.99 ± 0.06	37.8 ± 1.2	38285 ± 1166	1.71 ± 0.04	37.1 ± 1.4	2983.5 ± 0.7	5.2

Fit η_c(2S) Peak

fwetamvS15P50	
Entries	60
Mean	3.611
RMS	0.07938

Φ=4.65 rad

X^2/ndf=54/53

fwetamvS15P50	
Entries	60
Mean	3.611
RMS	0.07938

Φ=1.67 rad

X^2/ndf=54/53

X^2/ndf = 55/54 for "no interference"

$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	ϕ [rad]	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
2.17 ± 0.49	41.2 ± 9.3	17010 ± 3792	4.65 ± 0.07	23.1 ± 6.7	3634.8 ± 3.2	6.5
0.22 ± 0.05	4.1 ± 0.9	1695 ± 388	1.67 ± 0.22	23.0 ± 7.1	3634.8 ± 3.2	6.5

Fit Summary (no interference)

	1S	2S
Mass[MeV/c^2]	2981.4$\pm$0.5$\pm$0.4	3633.7$\pm$2.3$\pm$1.9
PDG	2980.4 $\pm$1.2	3638$\pm$4
CLEO	2981.8 $\pm$1.3 $\pm$ 1.5	3642.9$\pm$3.1$\pm$1.5
Babar	2982.5 $\pm$1.1 $\pm$0.9	3630.8$\pm$3.4$\pm$1.0
Width[MeV/c^2]	36.6$\pm$1.5$\pm$2.0	19.1$\pm$6.9$\pm$6.0
PDG	25.5$\pm$3.4	14$\pm$7
CLEO	24.8$\pm$3.4$\pm$3.5	6.3$\pm$12.4$\pm$4.0
Babar	34.3$\pm$2.3$\pm$0.9	17.0$\pm$8.3$\pm$2.5
$\Gamma_{\gamma\gamma}$[keV]	7.48$\pm$0.20$\pm$0.59$\pm$2.09	0.59$\pm$0.13$\pm$0.07$\pm$0.17
PDG	6.7$\pm$0.9	-------
CLEO	7.4$\pm$0.4 $\pm$0.5 $\pm$2.3	1.3$\pm$0.6
$\Gamma_{\gamma\gamma}$Br[keV]	142.1$\pm$3.8$\pm$11.2	11.2$\pm$2.4$\pm$1.3
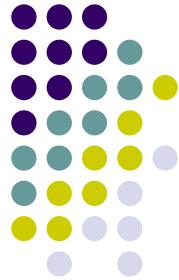
Fit Summary
(Comparison with "with interference")

	1S	2S
Mass[MeV/c²] $\phi > \pi$	2983.6±0.7±0.5	3634.8±3.2±2.3
$\Phi < \pi$	2983.5±0.7±0.5	3634.8±3.2±2.5
no interference	2981.4±0.5±0.4	3633.7±2.3±1.9
Width[MeV/c²] $\phi > \pi$	37.2±1.4±2.0	23.0±6.7±6.6
$\Phi < \pi$	37.1±1.4±2.0	23.0±7.1±6.6
no interference	36.6±1.5±2.0	19.1±6.9±6.0
$\Gamma_{\gamma\gamma}$[keV] $\phi > \pi$	16.5±0.4±1.5±4.6	2.16±0.49±0.52±0.60
$\phi < \pi$	1.99±0.06±0.15±0.56	0.22±0.05±0.05±0.06
no interference	7.48±0.20±0.59±2.09	0.59±0.13±0.07±0.17

Systematic error from choice of normalization is included in "with interference"

Summary

- **We have measured η_c(1S) and η_c(2S) mesons using 483/fb data sample.**

  - **Obtained parameters are consistent with previous measurements.**

  - **Another fits are performed with taking extreme interference effect into account**

    - **Background is estimated for each 20MeV/c^2 bin using pt-balance distribution to extract continuum**

      - **Magnitudes of the background differ depending on normalization but less sensitivity to the peak parameters**

    - **Interference between the peak and continuum is included in both 1S and 2S fits**

      - **Two solutions are found with relative phase difference ~3**

        - **Gives 1 order difference of the two-photon decay width**
        - **Phase are more or less same between 1S and 2S**
        - **Mass, Width are more or less same between the two solutions**

Comparison with other cuts

1S

ptb [MeV/c]	norm [MeV/c]	$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	ϕ [rad]	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
50	30	16.35 ± 0.44	310.6 ± 8.3	314967 ± 8228	4.62 ± 0.02	37.2 ± 1.5	2983.2 ± 0.8	5.17
100	15	15.87 ± 0.39	301.6 ± 7.3	305751 ± 7280	4.60 ± 0.02	37.3 ± 1.4	2983.6 ± 0.7	5.15
100	30	16.53 ± 0.41	314.0 ± 7.7	318315 ± 7676	4.61 ± 0.02	37.2 ± 1.4	2983.6 ± 0.7	5.15
100	50	16.90 ± 0.42	321.1 ± 8.0	325511 ± 7946	4.62 ± 0.02	36.9 ± 1.4	2983.5 ± 0.7	5.15

ptb [MeV/c]	norm [MeV/c]	$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	ϕ [rad]	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
50	30	1.68 ± 0.06	31.8 ± 1.1	32287 ± 1069	1.69 ± 0.04	37.0 ± 1.6	2983.1 ± 0.7	5.17
100	15	2.08 ± 0.06	39.5 ± 1.2	40011 ± 1223	1.72 ± 0.04	37.1 ± 1.4	2983.5 ± 0.7	5.15
100	30	1.99 ± 0.06	37.8 ± 1.2	38285 ± 1166	1.71 ± 0.04	37.1 ± 1.4	2983.5 ± 0.7	5.15
100	50	1.92 ± 0.06	36.4 ± 1.1	36940 ± 1128	1.70 ± 0.04	36.7 ± 1.4	2983.4 ± 0.7	5.15

2S

ptb [MeV/c]	norm [MeV/c]	$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	ϕ [rad]	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
50	15	2.17 ± 0.49	41.2 ± 9.3	17010 ± 3792	4.65 ± 0.07	23.1 ± 6.7	3634.8 ± 3.2	6.49
50	30	2.37 ± 0.67	45.1 ± 12.8	18630 ± 5233	4.66 ± 0.10	22.4 ± 7.6	3634.7 ± 4.3	6.49
100	15	2.02 ± 0.51	38.5 ± 9.8	15865 ± 4010	4.62 ± 0.07	19.8 ± 6.9	3637.2 ± 2.4	6.51

ptb [MeV/c]	norm [MeV/c]	$\Gamma_{\gamma\gamma}$ [keV]	$\Gamma_{\gamma\gamma}\mathcal{B}$ [eV]	Nevt	ϕ [rad]	Γ [MeV/c^2]	mass [GeV/c^2]	σ [MeV/c^2]
50	15	0.22 ± 0.05	4.1 ± 0.9	1695 ± 388	1.67 ± 0.22	23.0 ± 7.1	3634.8 ± 3.2	6.49
50	30	0.19 ± 0.04	3.6 ± 0.8	1481 ± 343	1.66 ± 0.22	22.4 ± 7.1	3634.7 ± 3.3	6.49
100	15	0.22 ± 0.05	4.3 ± 0.9	1763 ± 374	1.78 ± 0.28	19.9 ± 7.5	3637.2 ± 2.8	6.51

Check of Two body decays