

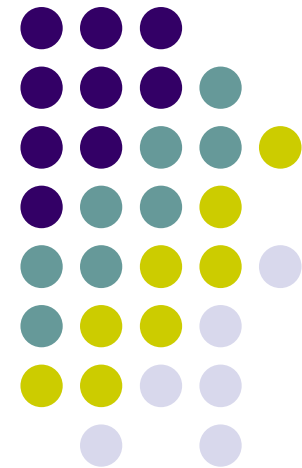
Recent Two-photon results at Belle



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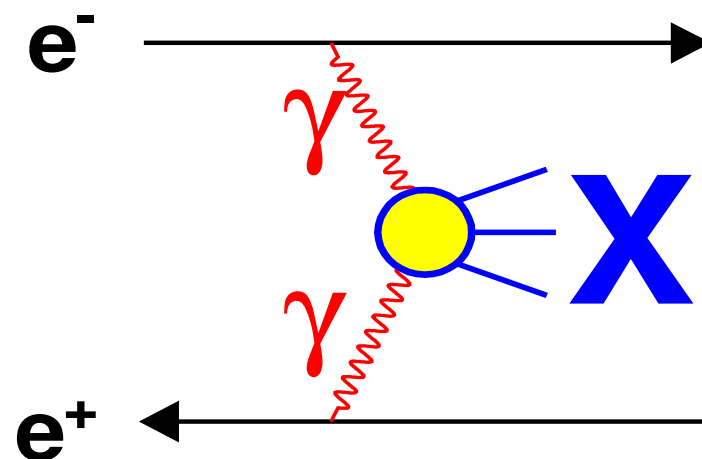
中澤秀介
國立中央大學、台灣

Lake Louise Winter Institute 2010
15th-20th February 2010 *Alberta, Canada*





Two-photon processes at Belle



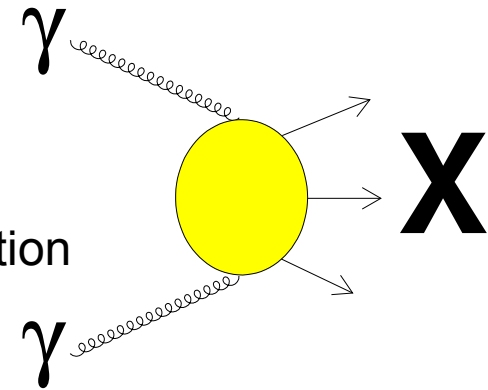
- **No-tag method**

- Apply tight transverse momentum cut to select exclusive two-photon events
- Small virtuality, almost real photons \rightarrow Measurement of $\Gamma_{\gamma\gamma}$
- Beam particles escape to beam pipes with small scattering angle
- $\gamma\gamma$ axis $\approx e^+e^-$ axis

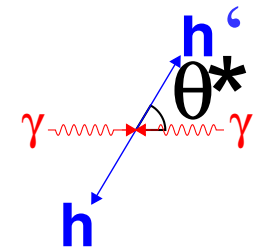
Two-photon Process



- Process with almost real photons
- (Differential) Cross section at $W \gtrsim 2.4$ GeV
 - pQCD leading-order calculation for hadron pair production
 - $\sigma(\gamma\gamma \rightarrow hh') \sim W^{-n}$ ($W \rightarrow \infty$)
 - $n = 6$ for charged meson pair
 - $n = 10$ for baryon pair
 - $d\sigma / d|\cos \theta^*| \sim \sin^{-4} \theta^*$ for charged meson pair
 - Consistent with $\gamma\gamma \rightarrow \pi^+\pi^-, K^+K^-$ for $W > 3.1$ GeV
 - Handbag model (non pQCD) $\sim \sin^{-4} \theta^*$ also for neutral pair
- Resonance study
 - $C=\text{even}$ ($\leftrightarrow C=\text{odd}$ for X in $e^+e^- \rightarrow X$), $J \neq 1$
 - Comparison with calculations for $\Gamma_{\gamma\gamma}$
 - $W \leq 3.0\text{GeV}$
 - Light meson study by Partial Wave Analysis
 - Provides information to solve light scalar meson puzzle
 - $W \geq 3.0\text{GeV}$
 - Charmonium study, XYZ search



$$W = M(\gamma\gamma) = M(X)$$



How to derive



Luminosity function

$$\sigma(e^+e^- \rightarrow e^+e^- X) = \int \sigma_{\gamma\gamma \rightarrow X}(W) \left[\frac{dL_{\gamma\gamma}}{dW} \right] dW$$

- Differential cross section and invariant mass spectrum for $\gamma\gamma \rightarrow h h'$

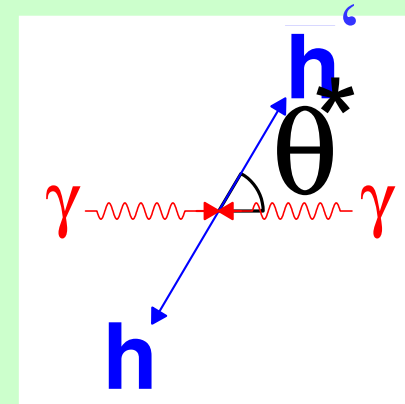
$$\frac{d\sigma}{d|\cos\theta^*|} = \frac{\Delta Y - \Delta B}{\Delta W \Delta|\cos\theta^*| \epsilon \frac{dL_{\gamma\gamma}}{dW} \int L dt}$$

$$W = M(\gamma\gamma) = M(X)$$

$$\sigma(W) = \sum \frac{d\sigma}{d|\cos\theta^*|} \Delta|\cos\theta^*|$$

- Two-photon decay width $\Gamma_{\gamma\gamma}$
 - For a narrow resonance

$$\Gamma_{\gamma\gamma}(R) Br(R \rightarrow X) = \frac{N_R m_R^2}{4(2J+1)\pi^2 \epsilon \frac{dL_{\gamma\gamma}}{dW}(m_R) \int L dt}$$



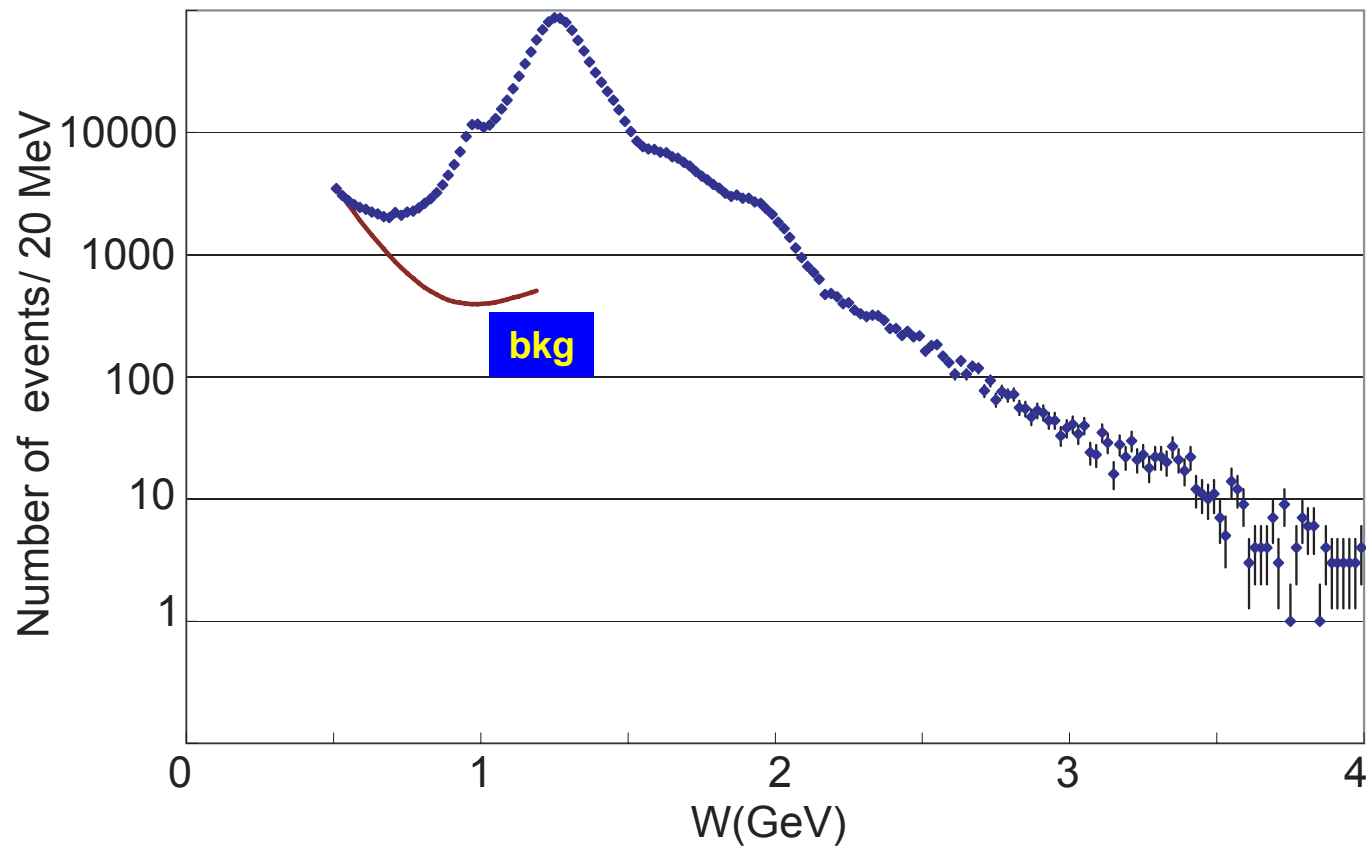
Contents

- $\gamma \gamma \rightarrow \pi^0 \pi^0$
- $\gamma \gamma \rightarrow \eta \pi^0$
- $\gamma \gamma \rightarrow \Phi \text{ J}/\psi$
- $\gamma \gamma \rightarrow \omega \text{ J}/\psi$



$$\gamma\gamma \rightarrow \pi^0\pi^0$$

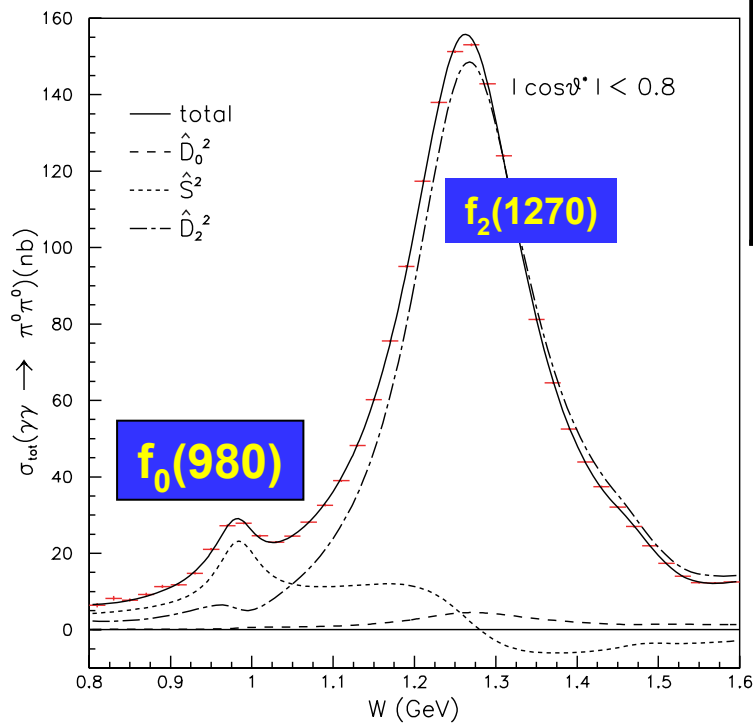
- PRD78, 052004 (95/fb) $W < 1.6\text{ GeV}$
- PRD79, 052009 (223/fb) $W > 1.7\text{ GeV}$
- $|\cos\theta^*| < 0.8$



$\gamma\gamma \rightarrow \pi^0\pi^0$: Partial Wave Analysis for $f_0(980)$ region



$$\frac{d\sigma}{4\pi d|\cos\theta^*|} = |SY_0^0 + D_0Y_2^0|^2 + |D_2Y_2^2|^2 = \hat{S}^2 |Y_0^0|^2 + \hat{D}_0^2 |Y_2^0|^2 + \hat{D}_2^2 |Y_2^2|^2$$



	$\pi^0\pi^0$	$\pi^+\pi^-$	PDG
M [MeV/c²]	$982.2 \pm 1.0^{+8.1}_{-8.0}$	$985.6^{+1.2}_{-1.5} {}^{+1.1}_{-1.6}$	980 ± 10
$\Gamma_{\gamma\gamma}$ [eV]	$286 \pm 17^{+211}_{-70}$	$205^{+95}_{-83} {}^{+147}_{-117}$	310^{+80}_{-110}

Model	$\Gamma_{\gamma\gamma}$ [keV]
uubar,ddbar	1.3-1.8
ssbar	0.3-0.5
KKbar molecule	0.2-0.6
Four-quark	0.27

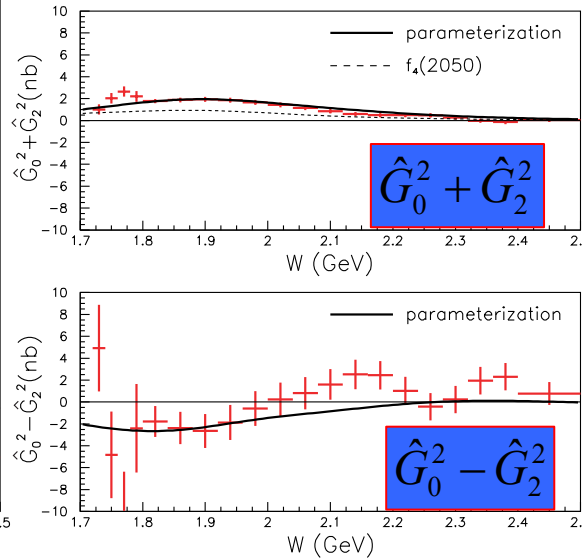
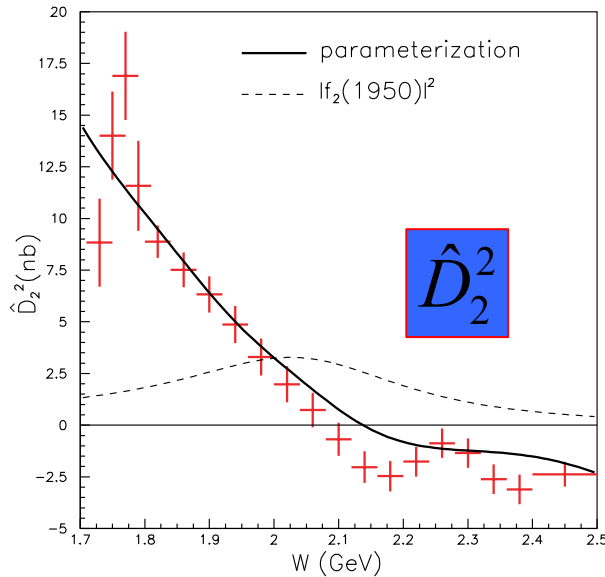
Consistent with $\pi^+\pi^-$ mode (PRD75,051101)
uubar, ddbar disfavored compared to other models

$\gamma\gamma \rightarrow \pi^0\pi^0$: $f_2(1950)$, $f_4(2050)$



$$\frac{d\sigma}{4\pi d|\cos\theta^*|} = |SY_0^0 + D_0Y_2^0 + G_0Y_4^0|^2 + |D_2Y_2^2 + G_2Y_4^2|^2$$

$$= \hat{S}^2 |Y_0^0|^2 + \hat{D}_0^2 |Y_2^0|^2 + \hat{D}_2^2 |Y_2^2|^2 + \hat{G}_0^2 |Y_4^0|^2 + \hat{G}_2^2 |Y_4^2|^2$$

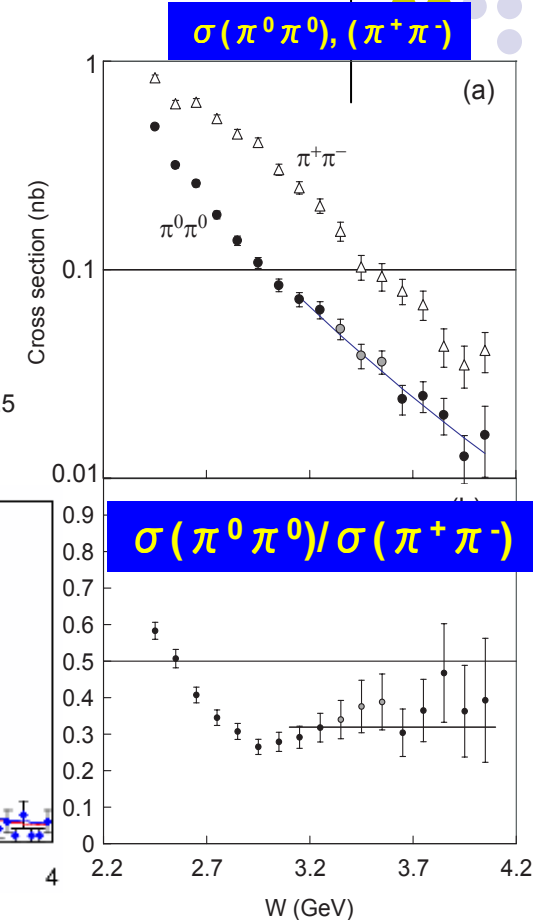
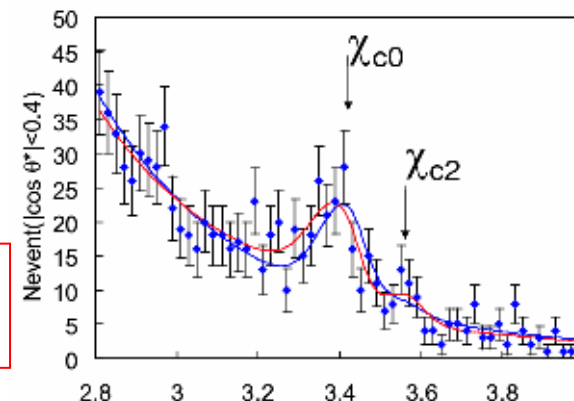
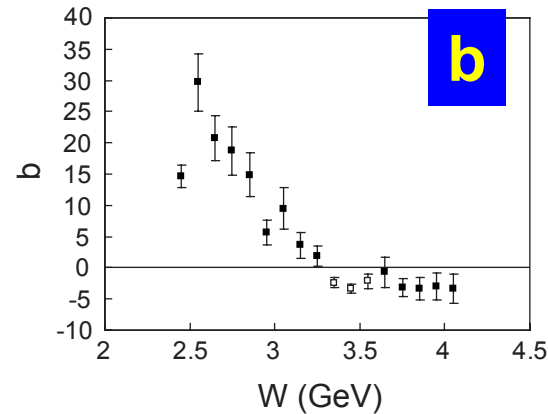
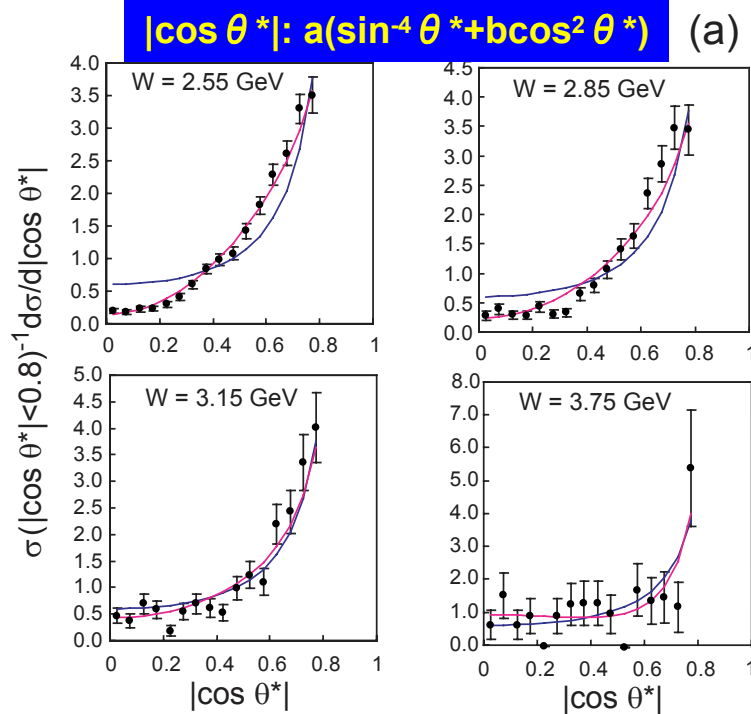
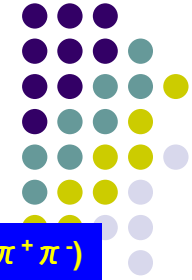


$M(f_4(2050))$	$1885^{+14}_{-13} \text{ MeV}/c^2$
$\Gamma(f_4(2050))$	$453 \pm 20 \text{ MeV}$
$\Gamma_{\gamma\gamma} B(\pi^0\pi^0)$	$7.7^{+1.2}_{-1.1} \text{ eV}$
$M(f_2(1950))$	$2038^{+13}_{-11} \text{ MeV}/c^2$
$\Gamma(f_2(1950))$	$441^{+27}_{-25} \text{ MeV}$
$\Gamma_{\gamma\gamma} B(\pi^0\pi^0)$	$54^{+23}_{-14} \text{ eV}$

	Nominal	Fixed $f_4(2050)$	No $f_4(2050)$	No $f_2(1950)$
χ^2 (ndf)	323.2(311)	594.4(313)	1397.8(315)	2306.8(315)

Inclusion of both $f_2(1950)$ and $f_4(2050)$ gives much better χ^2

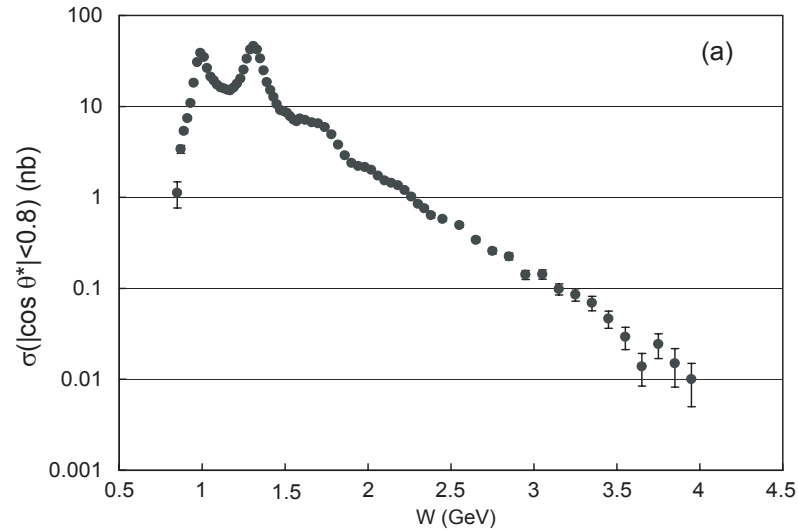
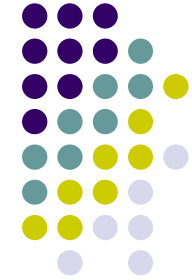
$\gamma\gamma \rightarrow \pi^0\pi^0$: Higher region



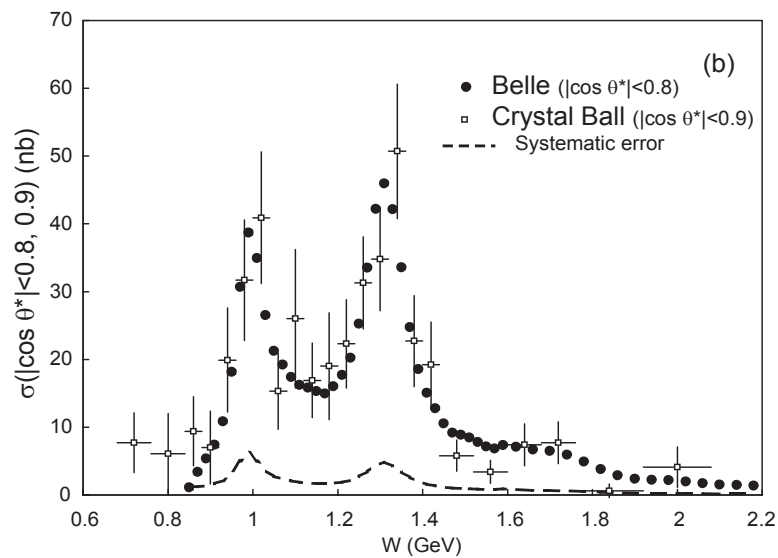
$\sigma \sim W^{-n}: n = 6.9 \pm 0.6 \pm 0.7$
 $\sigma(\pi^0\pi^0)/\sigma(\pi^+\pi^-) = 0.32 \pm 0.03 \pm 0.05$

- Significant **b** term contribution
- Cross section ratio slightly smaller than Isospin symmetry, 0.5
- χ_{c0} observed with 7σ

$$\gamma\gamma \rightarrow \eta\pi^0$$



- PRD80, 032001 (2009). 223/fb
- a_J resonances (Isospin=1)
- $|\cos \theta^*| < 0.8$

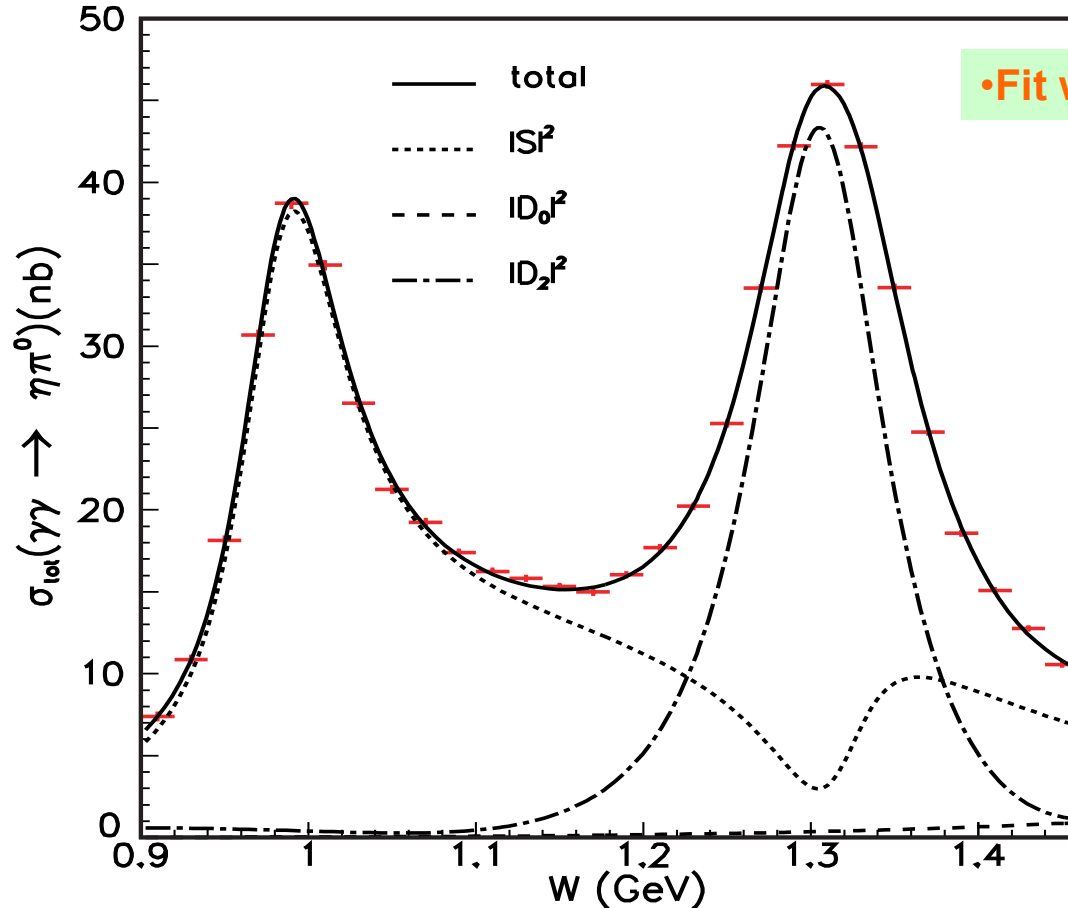
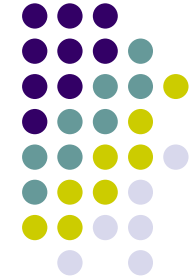


- $a_0(980)$, $a_2(1320)$, $a_2(1700)$ seen
- Consistent with Crystal Ball measurement (PRD33, 1847 (1986))

$\gamma\gamma \rightarrow \eta\pi^0$:

Partial Wave Analysis in $0.9 < W < 1.5$ GeV

$$\frac{d\sigma}{4\pi d|\cos\theta^*|} = |SY_0^0 + D_0Y_2^0|^2 + |D_2Y_2^2|^2 = \hat{S}^2 |Y_0^0|^2 + \hat{D}_0^2 |Y_2^0|^2 + \hat{D}_2^2 |Y_2^2|^2$$



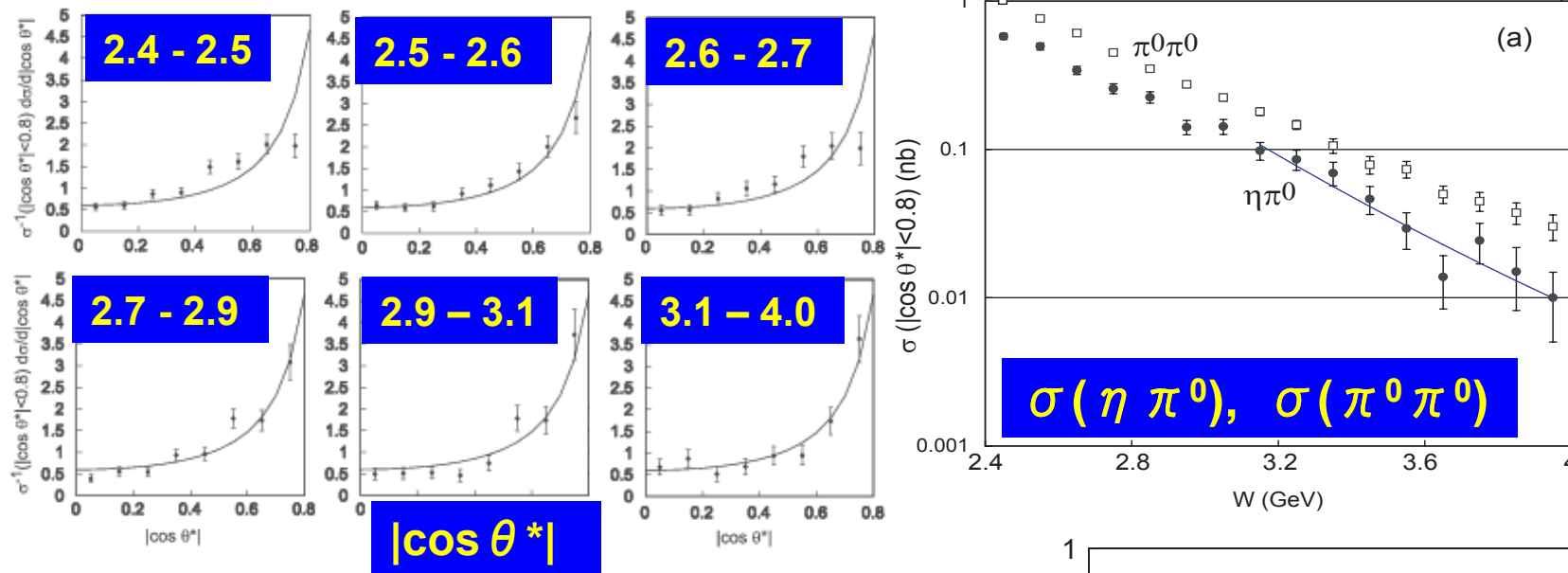
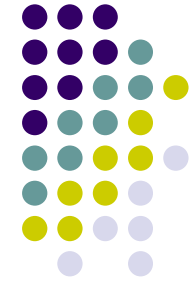
•Fit with $a_0(980)$, $a_2(1320)$ and $a_0(Y)$

$a_0(980)$	
M [MeV/c ²]	$982.3^{+0.6}_{-0.7} {}^{+3.1}_{-4.7}$
Γ [MeV]	$75.6 \pm 1.6 {}^{+17.4}_{-10.0}$
$\Gamma_{\gamma\gamma}$ [eV]	$128^{+3}_{-2} {}^{+502}_{-43}$
$a_0(Y)$	
M [MeV/c ²]	$1316.8^{+0.7}_{-1.0} {}^{+24.7}_{-4.6}$
Γ [MeV]	$65.0^{+2.1}_{-5.4} {}^{+99.1}_{-32.6}$
$\Gamma_{\gamma\gamma}$ [eV]	$432 \pm 6 {}^{+1073}_{-256}$

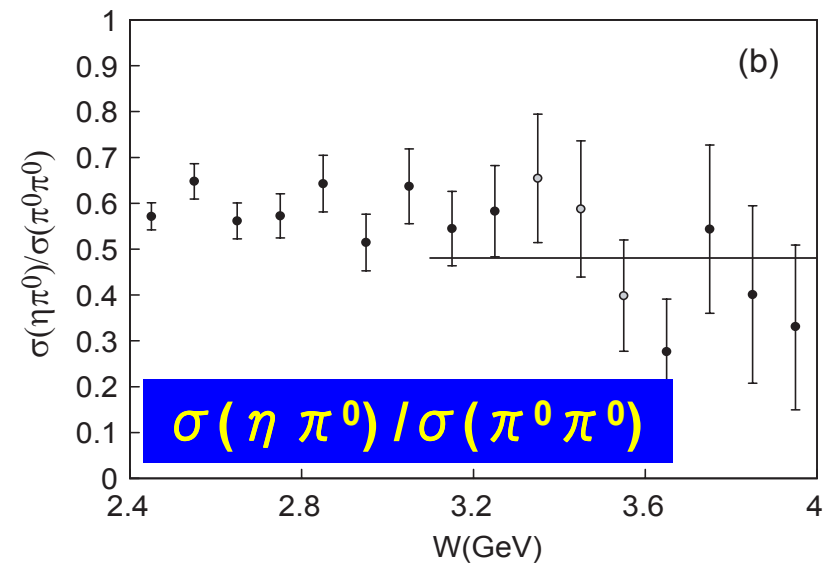
	Nominal	M($a_0(Y)$) = M($a_0(1450)$)	No $a_0(Y)$
χ^2 (ndf)	597.6/429	704.5/430	753.6/433

For $a_0(Y)$, nominal $a_0(1450)$ and background from $a_2(1320)$ disfavored

$\gamma\gamma \rightarrow \eta\pi^0$: Higher region

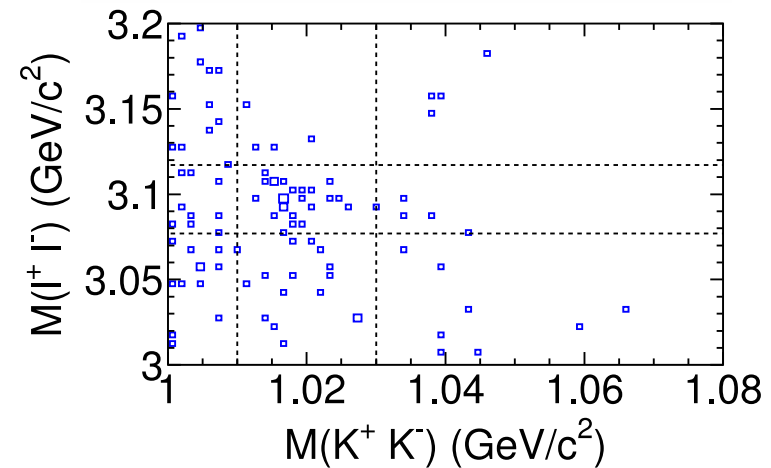
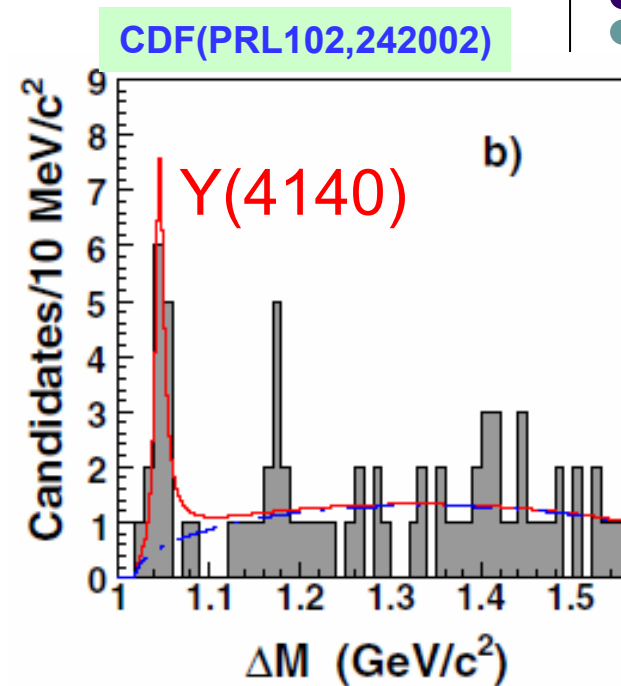
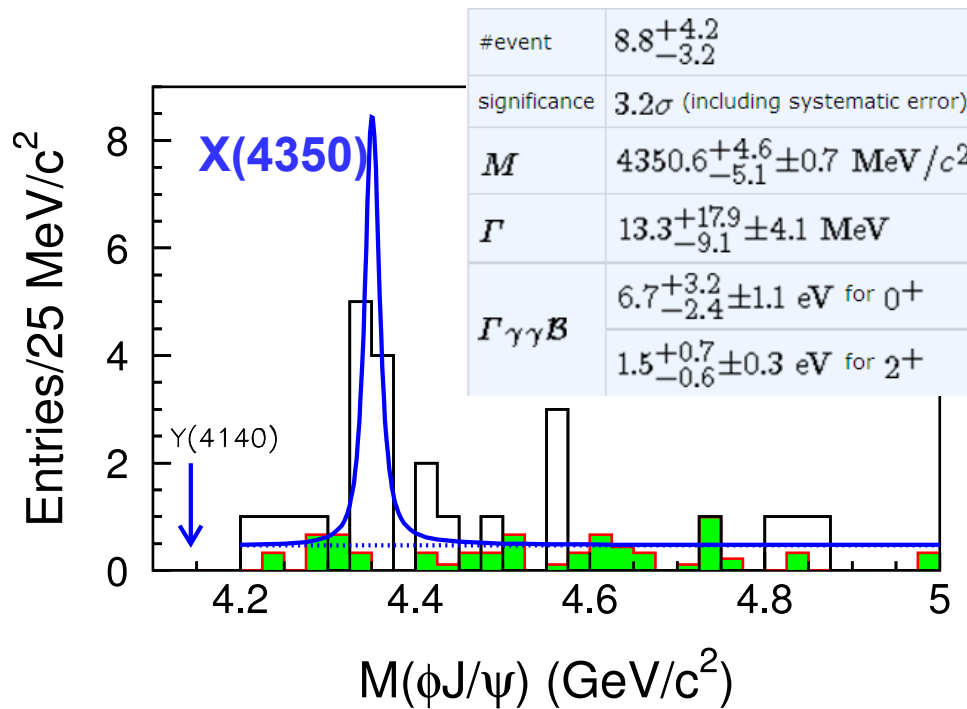


- Consistent with $\sin^{-4}\theta^*$ for $W > 2.7$ GeV
- W^{-n} dependence of σ
 $n = 10.5 \pm 1.2 \pm 0.5$
 consistent with KsKs ($10.5 \pm 0.6 \pm 0.5$)
- $\sigma(\eta\pi^0) / \sigma(\pi^0\pi^0) = 0.48 \pm 0.05 \pm 0.04$
 - Not conclusive whether constant or not



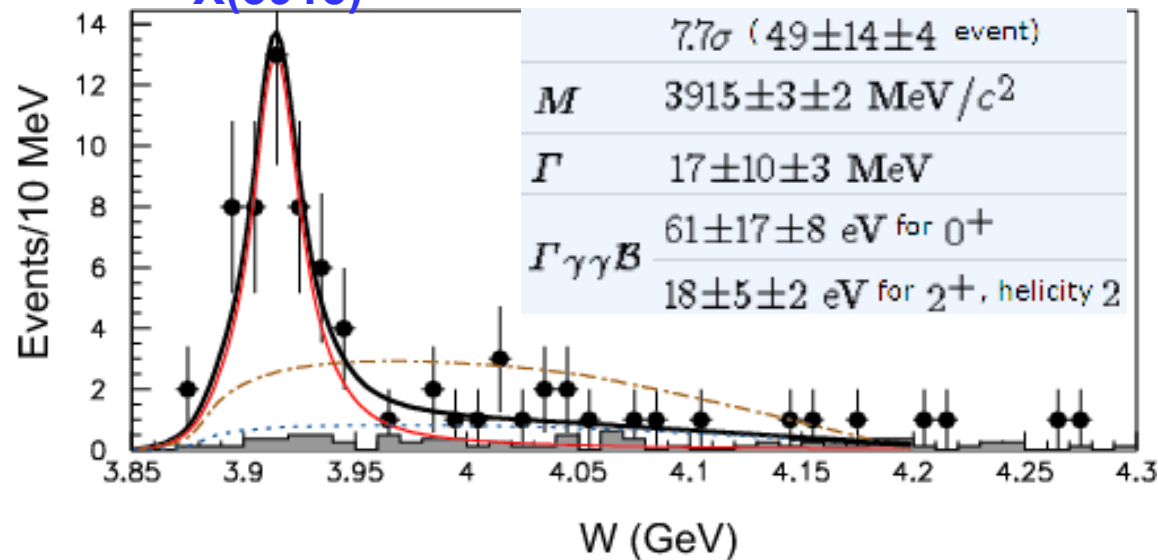
$$\gamma\gamma \rightarrow \Phi \text{ J}/\psi$$

- 825/fb
- No signal of Y(4140)
 - $D_s^{*-} D_s^{*-}$ molecule disfavored
- Evidence for a new structure X(4350)
 - Tetraquark?, $D_s^{*-} D_{s0}^{*-}$ molecular?, χ_{c2}'' ?



$$\gamma\gamma \rightarrow \omega J/\psi$$

X(3915)



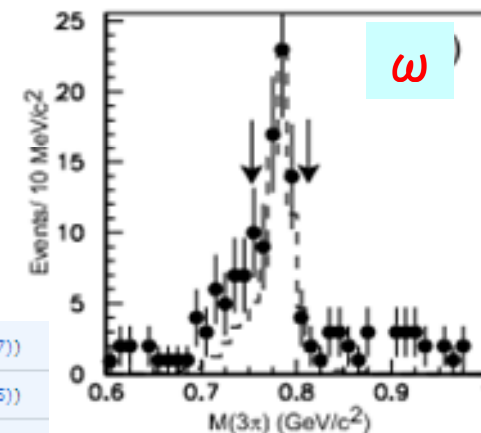
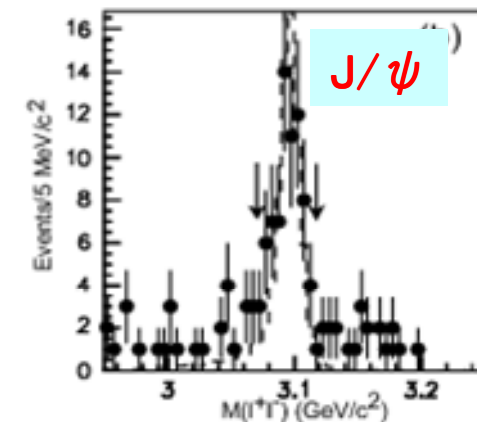
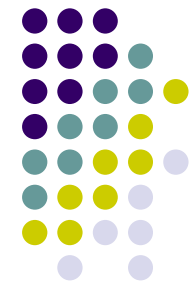
- Comparable with Y(3940) and Z(3930)
- Measured $\Gamma_{\gamma\gamma}(X) \Gamma_{\omega J/\psi}(X)$ compatible with D^*D^* state

XYZ near X(3915)

X(3940) $0^{?+}$	$e^+e^- \rightarrow J/\psi X$	$3943 \pm 6 \pm 6$ MeV/ c^2	< 52 MeV	Belle(PRL98, 082001 (2007))
Y(3940) $?^{?+}$	$B^- \rightarrow K^- Y, Y \rightarrow \omega J/\psi$	$3943 \pm 11 \pm 13$ MeV/ c^2	$87 \pm 22 \pm 26$ MeV	Belle(PRL94, 182002 (2005))
		$3914.6^{+3.8}_{-3.4} \pm 2.0$ MeV/ c^2	$34^{+12}_{-8} \pm 5$ MeV	BeBe(PRL101, 182001 (2008))
Z(3930) 2^{++}	$\gamma\gamma \rightarrow Z, Z \rightarrow D\bar{D}$	$3929 \pm 5 \pm 2$ MeV/ c^2	$29 \pm 10 \pm 2$ MeV	Belle(PRL96, 082003 (2006))

Feb 17, 2010

Recent Two-Photon results at Belle H.
Nakazawa (NCU)

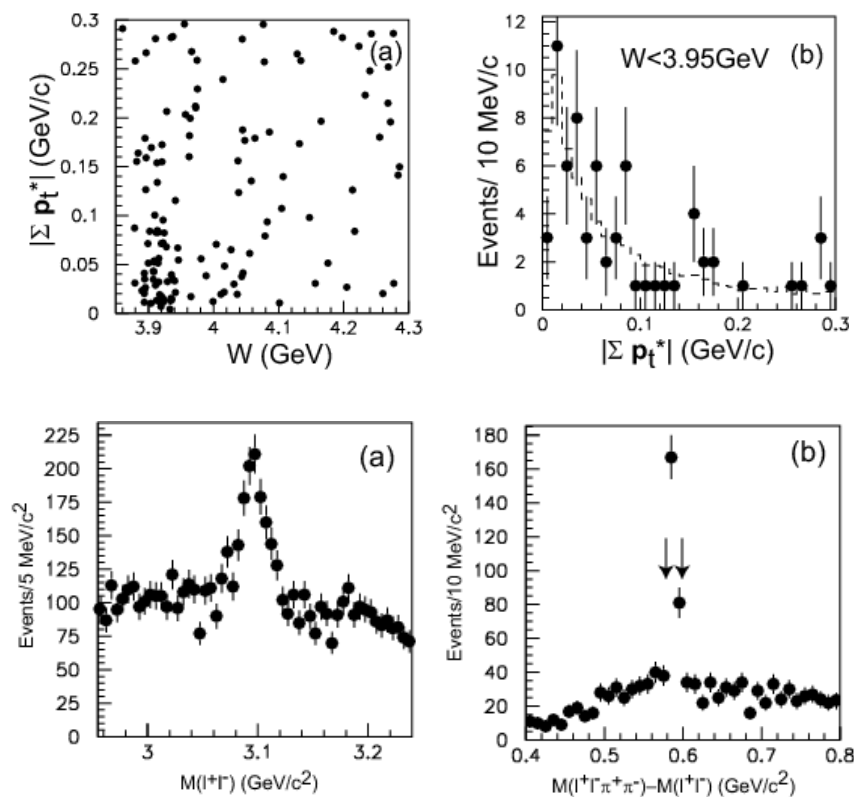


Summary



- **Pure neutral final states $\pi^0 \pi^0$ and $\eta \pi^0$ have been studied in two-photon process**
 - Light quark resonances are studied by Partial Wave Analysis
 - χ_{cJ} mesons are observed in $\pi^0 \pi^0$ final states
 - Differential cross section and cross section are compared with QCD predictions
- **X(3915) has been observed in $\gamma \gamma \rightarrow \omega J/\psi$**
 - Comparable parameters with Y(3940) and Z(3930)
- **Evidence of X(4350) was found in $\gamma \gamma \rightarrow \Phi J/\psi$**
 - A new structure (?)
 - No signal of CDF Y(4140)

Pt-balance



Entries/20 MeV/c

