Studies of Light Quark Mesons in $\gamma\gamma$ Processes at Belle

Simon Eidelman

Budker Institute of Nuclear Physics SB RAS
and Novosibirsk State University,
Novosibirsk, Russia

Outline

1. Meson Spectroscopy
2. Transition form factors
3. Conclusions

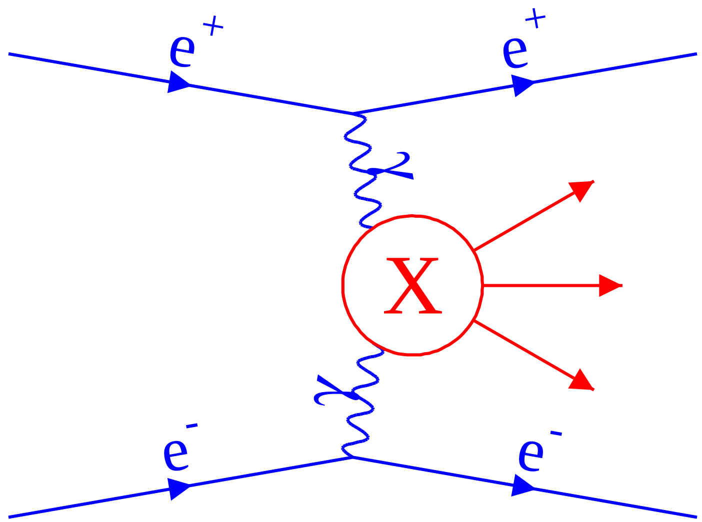
General

- Two-photon collisions provide a complementary way of studying mesons (decays of heavier D, B, τ, initial state radiation, continuum, ...)
- e^+e^- are an ideal "clean" place for $\gamma\gamma$, but even LHC starts contributing (recent work by ATLAS)
- Spectroscopy for different quantum numbers (M, Γ, $\Gamma_{\gamma\gamma}$) (no-tag, both $e^\pm$ not detected, small $q^2_{1,2}$, quasireal photons)
- Two-photon width reflects the internal structure and origin
- QCD tests, transition form factors (single-and double-tag)

Predictions for the two-photon width of the $f_0(980)$

Origin	$u\bar{u}, d\bar{d}$	$s\bar{s}$	$K\bar{K}$	Tetraquark
$\Gamma_{\gamma\gamma}$, eV	1300-1800	300-500	200-600	270

Basic Features of Two-Photon Collisions



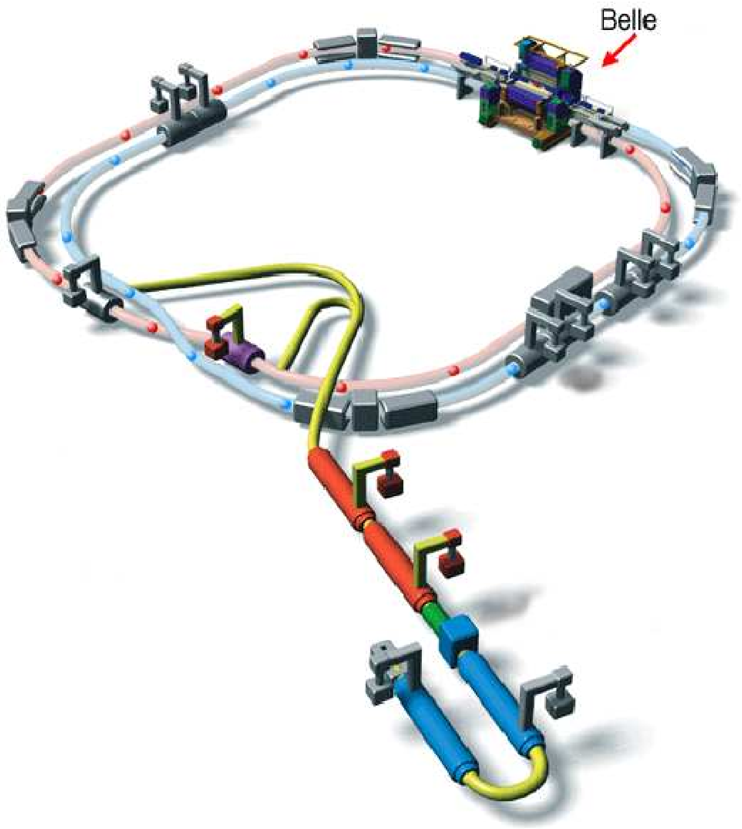
W – $\gamma\gamma$ (X) c.m. energy, q_1^2, q_2^2 – 4-momenta squared of virtual photons,

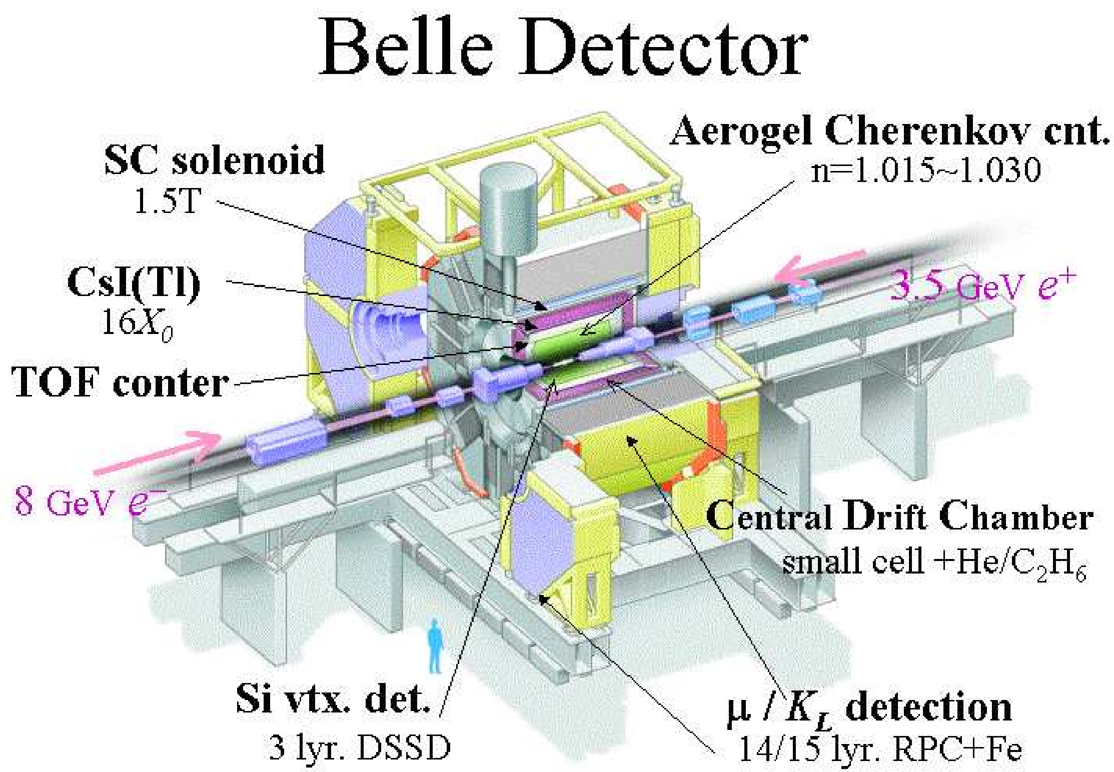
θ^* – X polar c.m. angle with respect to e^+e^-,

Particles produced in $\gamma\gamma$ collisions have $C = +1$,

The produced system has $E_{\rm tot} \ll \sqrt{s} = 2E$ and low p_t

Belle Experiment



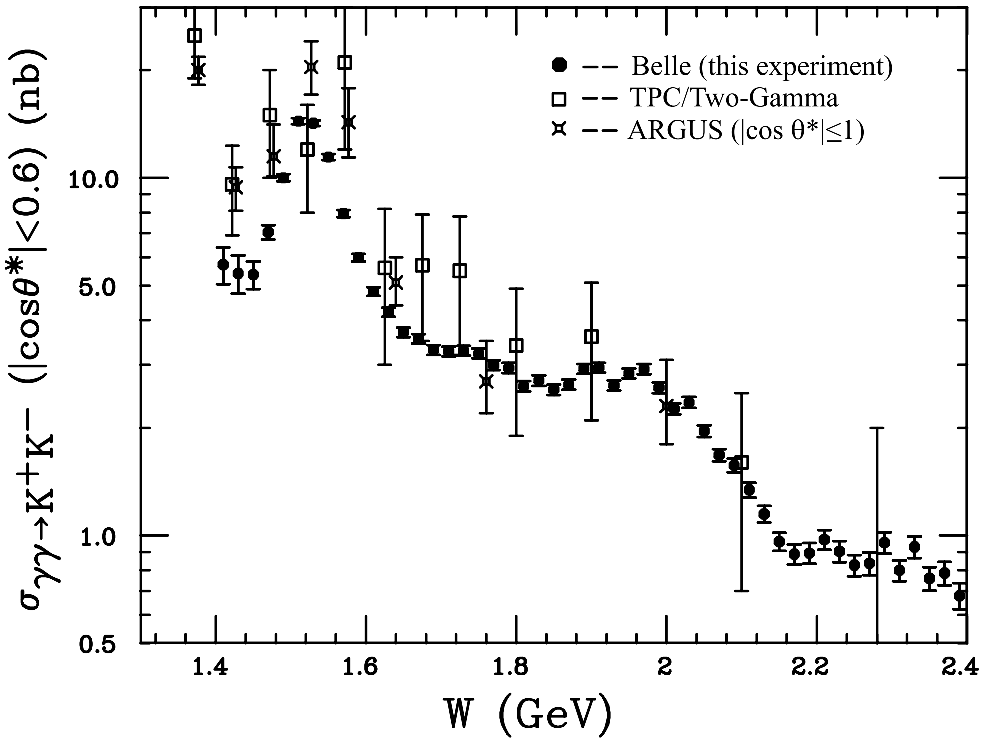


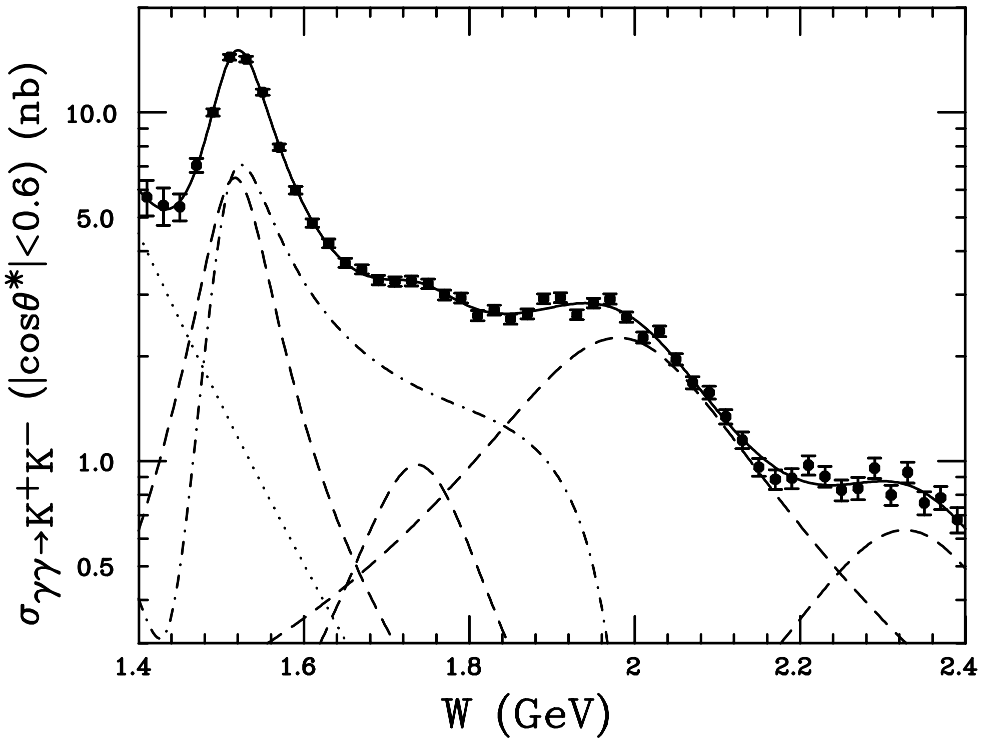
World highest luminosity of 2.11×10^{34} cm^{-2} s^{-1}, $\int Ldt \sim 1$ ab^{-1}

Studies of Light-Quark Mesons at Belle

Final state	$\int Ldt$, fb^{-1}	W, GeV	Reference
K^+K^-	67	1.4-2.4	EPJC 32, 323 (2003)
$\pi^+\pi^-$	87.7	2.4-4.1	PRD 75, 051101 (2007)
$\pi^0\pi^0$	95	0.6-4.0	PRD 78, 052004 (2008)
	223	0.6-4.1	PRD 79, 052009 (2009)
$\eta\pi^0$	223	0.84-4.0	PRD 80, 032001 (2009)
$\eta\eta$	393	1.1-3.8	PRD 82, 114031 (2010)
$\omega\omega$, $\omega\phi$, $\phi\phi$	870	1.6-4.0	PRL 108, 232001 (2012)
$\eta'\pi^+\pi^-$	673	1.4-3.4	PRD 86, 052002 (2012)
$K_S^0K_S^0$	972	1.0 - 4.0	PTEP 2013, 123C01 (2013)

$\gamma\gamma \to K^+K^-$

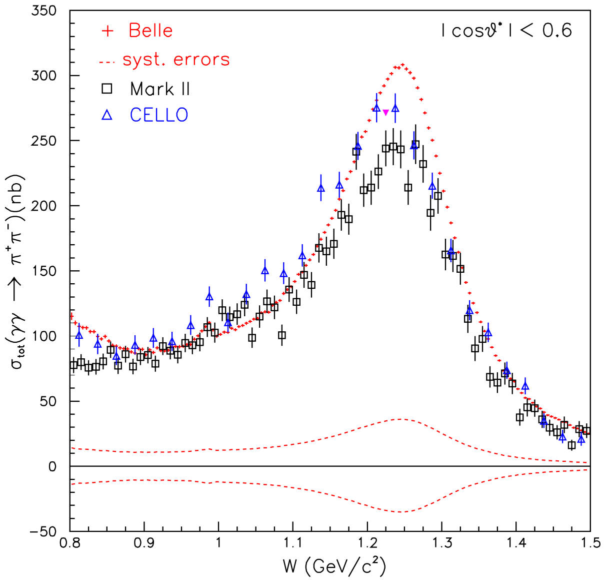


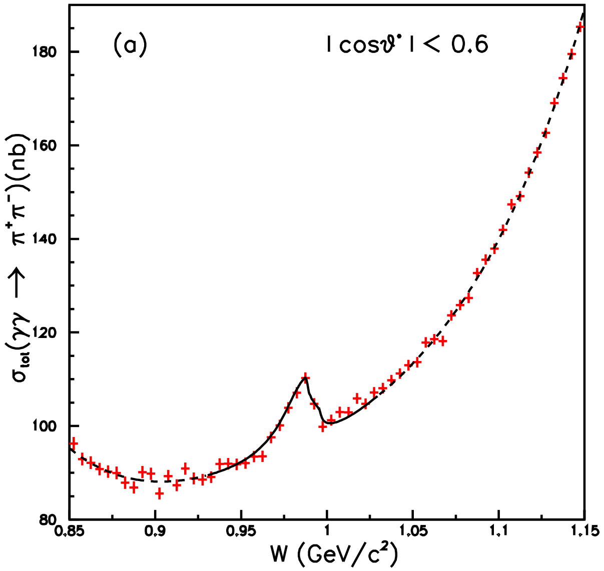


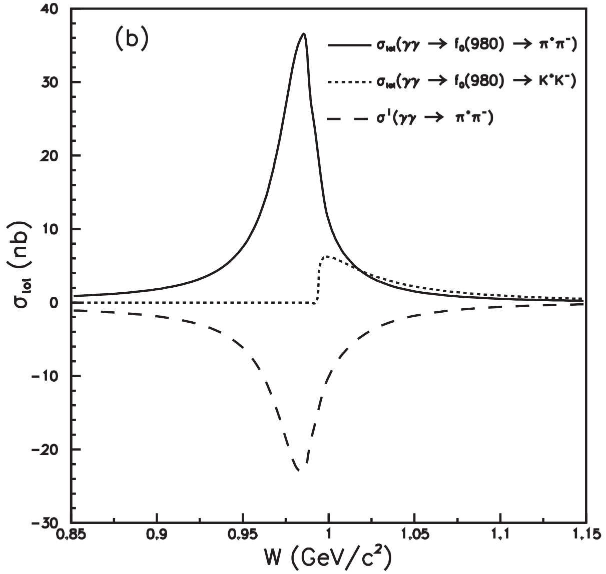
$f_2'(1525)$ and 3 more states at 1.7, 2.0 and 2.3 GeV (tensors?)

K. Abe et al., Eur. Phys. J. C 32, 323 (2003)

$\gamma\gamma \to \pi^+\pi^-$ and $f_0(980)$





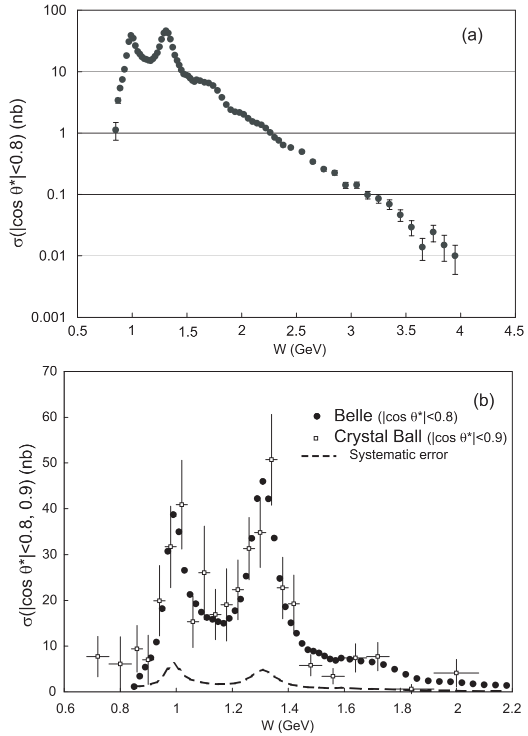


The data confirm the "peak" solution of

M. Boglione and M.R. Pennington, Eur. Phys. J. C 9, 11 (1999)

T. Mori et al. (Belle Collab.), Phys. Rev. D 75, 051101 (2007)

$\gamma\gamma \to \eta\pi^0$



$a_0(980), a_2(1320)$ seen, a hint of $a_2(1700)$

Instead of $a_0(1450)$ a state at 1317 MeV, $a_0(Y)$, seen

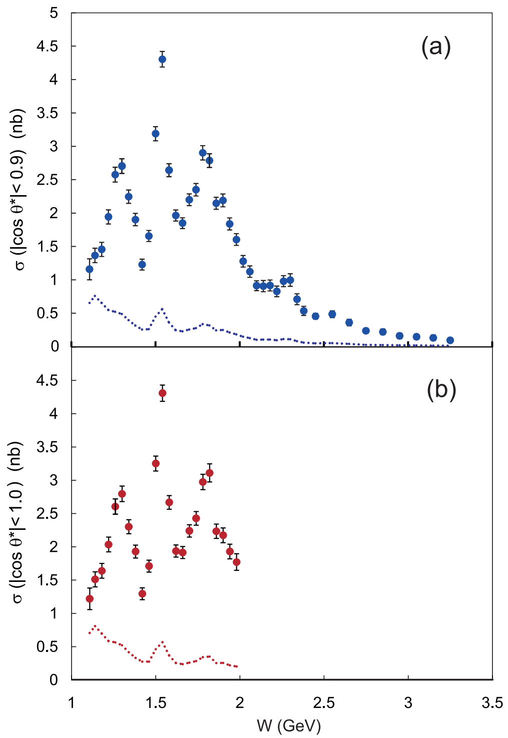
S. Uehara et al. (Belle Collab.), Phys. Rev. D 80, 032001 (2009)

Two-photon Widths of the $f_0(980)$ and $a_0(980)$

State	$f_0(980),\ \pi^+\pi^-$	$f_0(980),\ \pi^0\pi^0$	$a_0(980)$
Mass, MeV	$985.6^{+1.2+1.1}_{-1.5-1.6}$	$982.2 \pm 1.0^{+8.1}_{8.0}$	$982.3^{+0.6+3.1}_{-0.7-4.7}$
$\Gamma(\pi\pi)$, MeV	$51.3^{+20.9+13.2}_{-17.7-\ 3.8}$	$66.9 \pm 2.2^{+17.6}_{-12.5}$	$75.6 \pm 1.6^{+17.4}_{-10.0}$
$\Gamma(\gamma\gamma)$, eV	$205^{+95+147}_{-83-117}$	$286 \pm 17^{+211}_{-70}$	$128^{+3+502}_{-2-\ 43}$

$u\bar{u}, d\bar{d}$ structure of the $f_0(980)$ excluded

$\gamma\gamma \to \eta\eta$



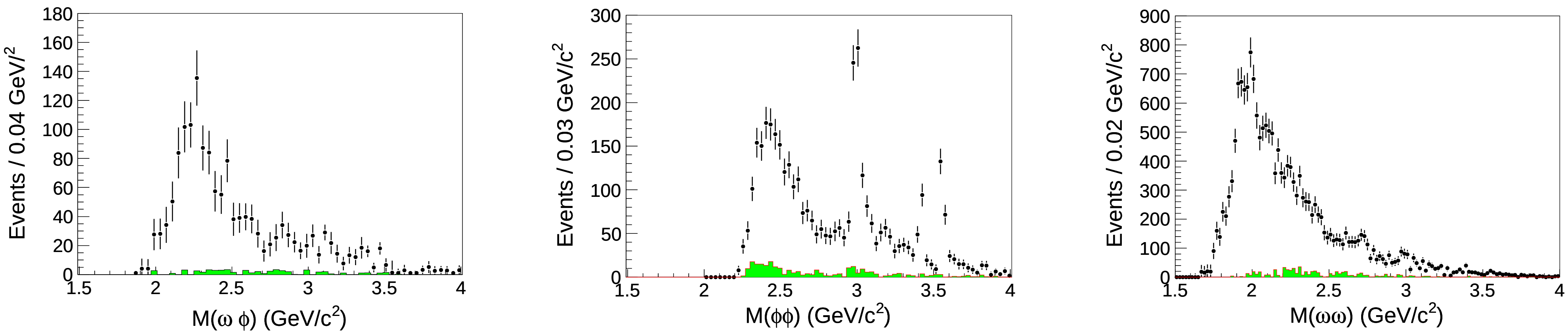
$f_2(1270)$, $f_2'(1525)$ observed, evidence for f_2 at 1737 MeV

A broad ($\sim$ 480 MeV) scalar structure at 1262 MeV,

$f(1370)$ or $f_0(1500)$ or mixture?

S. Uehara et al., Phys. Rev. D 82, 114031 (2010)

$\gamma\gamma \to \omega\omega,\ \omega\phi,\ \phi\phi$



Structures at 1.91 ($\omega\omega$), 2.2 ($\omega\phi$), 2.35 GeV ($\phi\phi$), 0^{++} or 2^{++}

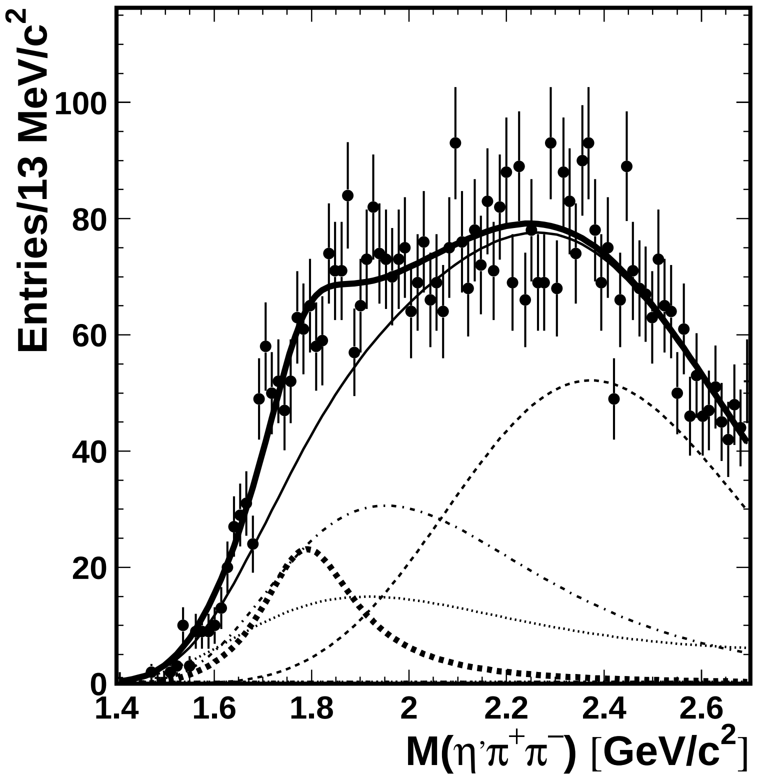
Theory: $\sim 1/W^6$, experiment – steeper,

$\sigma(\omega\omega) \ll \sigma(\phi\phi) \ll \sigma(\omega\phi)$, correctly predicts $\sigma(\phi\phi)$, $\sigma(\omega\phi)$ at 4 GeV,

but in experiment $\sigma(\omega\omega)$ is too high, V. Chernyak, arXiv:1212.1304

Z.-Q. Liu et al.(Belle Collab.), Phys. Rev. Lett. 108, 232001 (2012)

$\gamma\gamma \to \eta'\pi^+\pi^-$

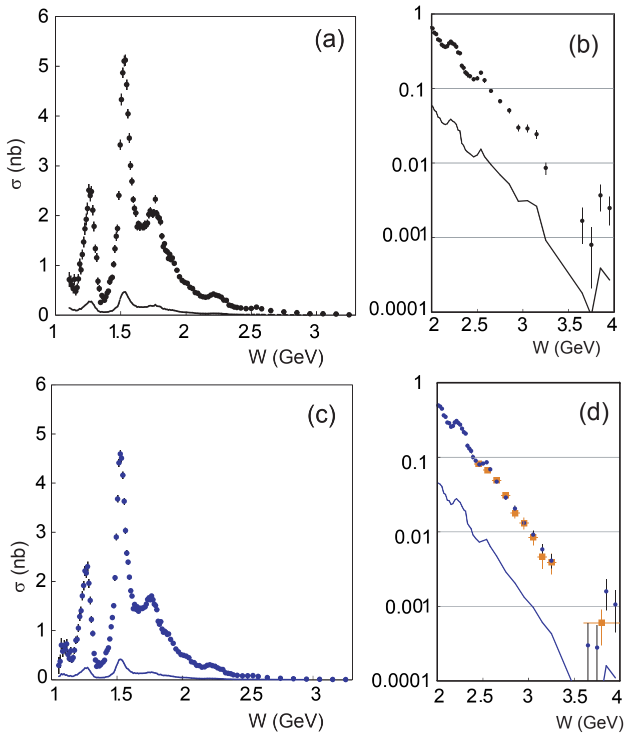


$\eta(1760) \to \eta'\pi^+\pi^-$ observed for the first time

No evidence found for $X(1835)$ observed by BES near $p\bar{p}$ threshold

C.C. Zhang et al. (Belle Collab.), Phys. Rev. D 86, 052002 (2012)

$\gamma\gamma \to K_S^0 K_S^0$ – I

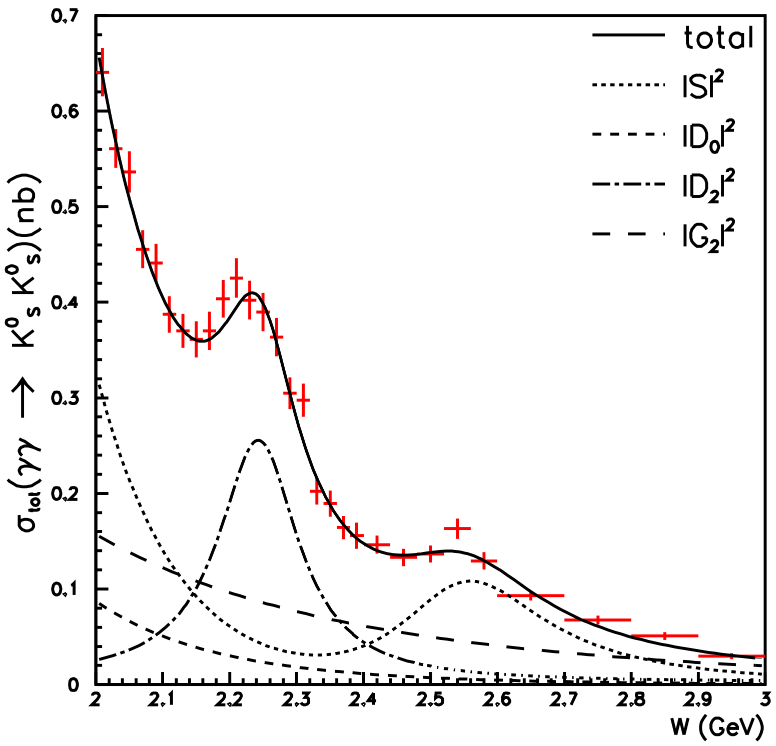


Destructive interference between $f_2(1270)$ and $a_2(1320)$ observed

Parameters of $f_2'(1525)$ determined, presence of $f_0(1710)$ favored

S. Uehara et al., PTEP 2013, 123C01 (2013)

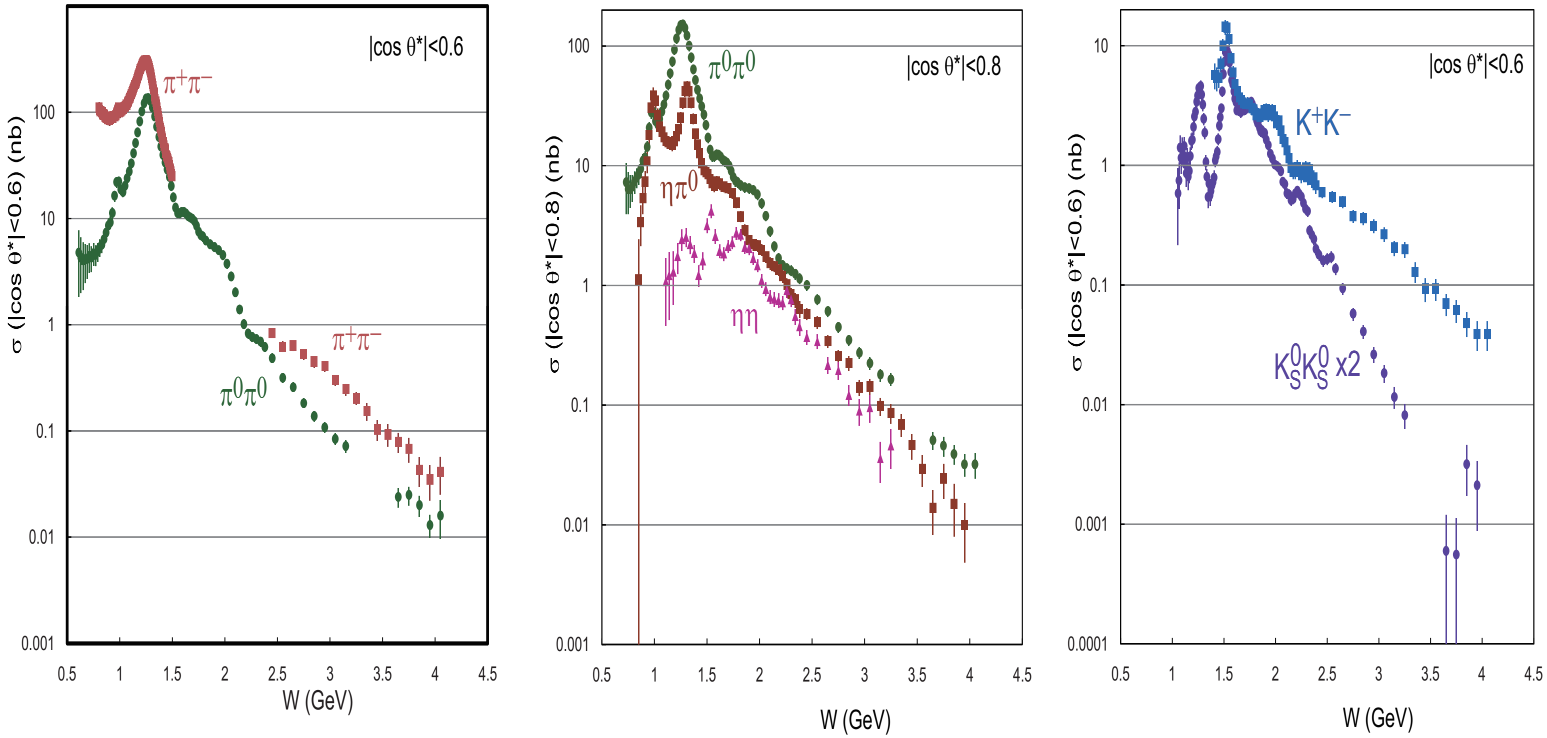
$\gamma\gamma \to K_S^0 K_S^0$ –II



Evidence for $f_2(2200)$ and first evidence for $f_0(2500)$

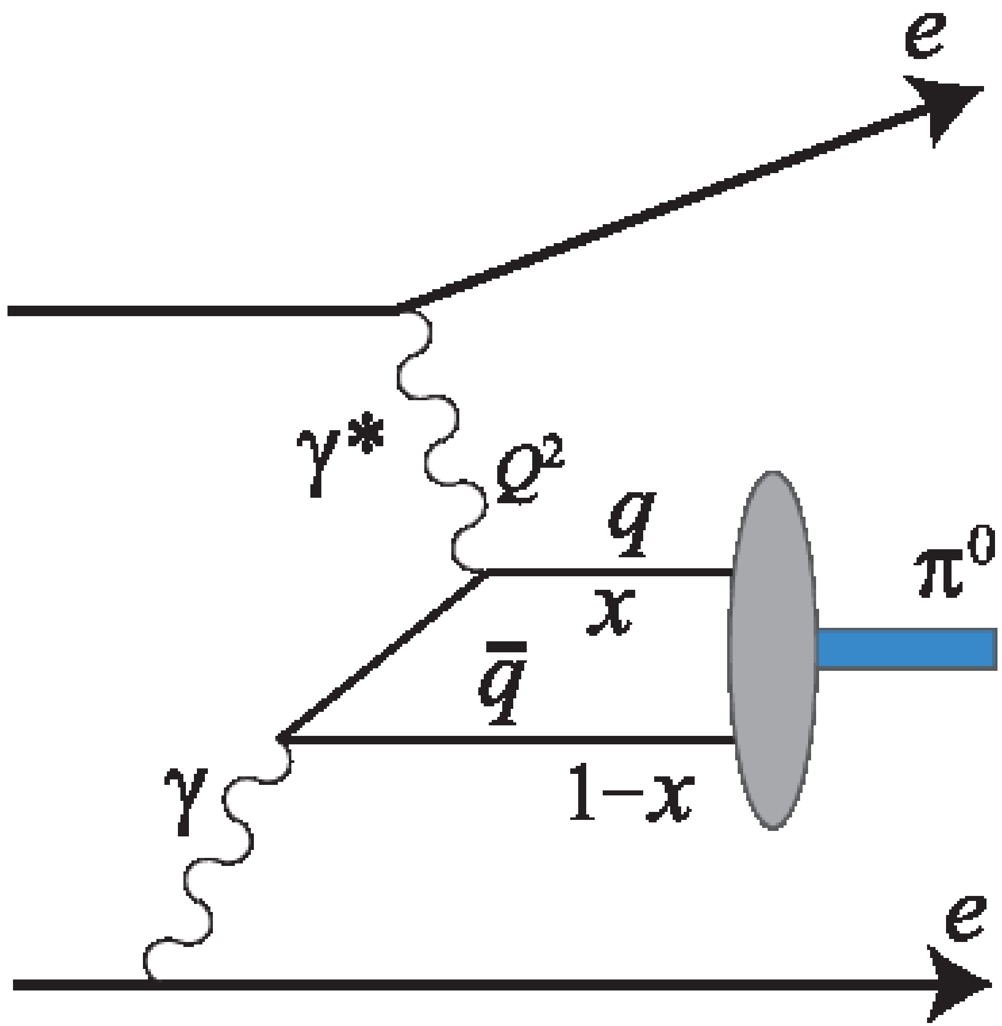
S. Uehara et al., PTEP 2013, 123C01 (2013)

Summary of Spectroscopy Studies



~ 20 structures observed in 8 final states!

The Pion Distribution Amplitude – I



The Pion Distribution Amplitude – II

At sufficiently high Q^2 the TFF $F(Q^2)$

$$F(Q^2) = \frac{\sqrt{2} f_\pi}{3} \int_0^1 dx \frac{\phi_\pi(x)}{x Q^2} + \mathcal{O}\left(1/Q^4\right), \quad (1)$$

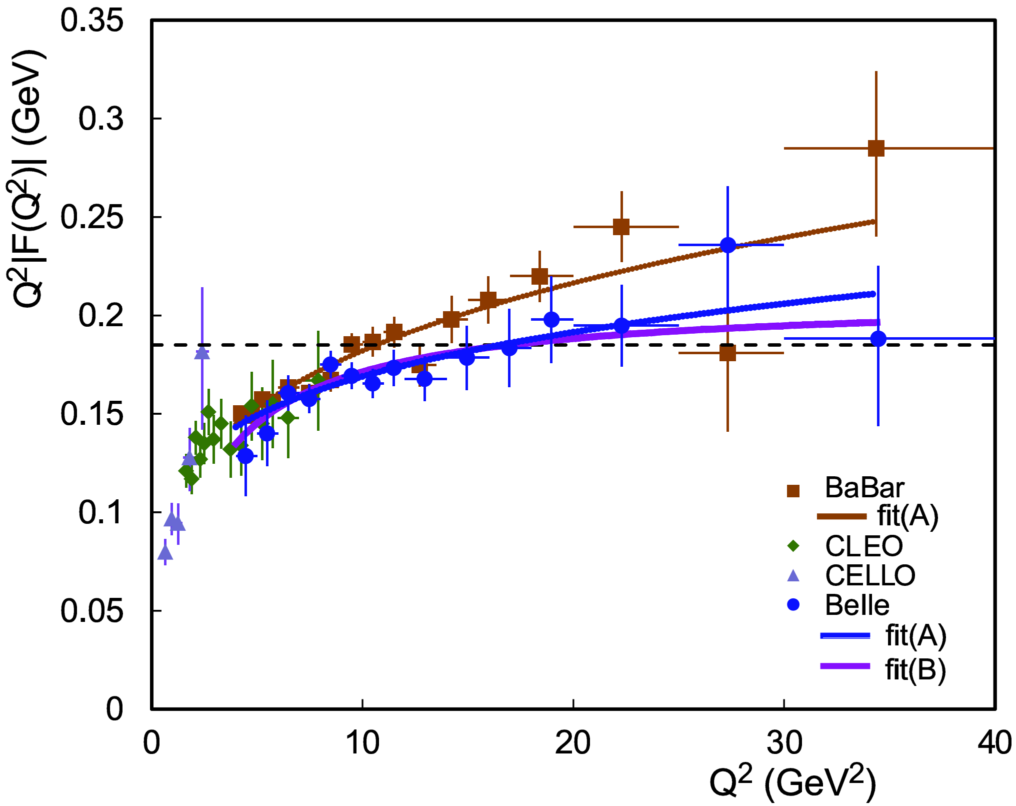
where $f_\pi \simeq 0.131$ GeV is the pion decay constant, x is the fraction of momentum carried by a quark (q) or antiquark ($\bar{q}$) in the parent pion, $\phi_\pi(x, Q^2)$ is the leading-twist pion distribution amplitude (DA) at x and Q^2 in all hard exclusive processes with a pion.

The asymptotic pion DA is $\phi_\pi^{\mathrm{asy}} = 6x(1-x)$, so that $Q^2 F(Q^2)$ at $Q^2 \to \infty$ is

$$Q^2 F(Q^2) = \sqrt{2} f_\pi \simeq 0.185 \text{ GeV}. \quad (2)$$

Early measurements from CELLO and CLEO support this:
the asymptotic value is approached from below.

$\gamma\gamma^* \to \pi^0$

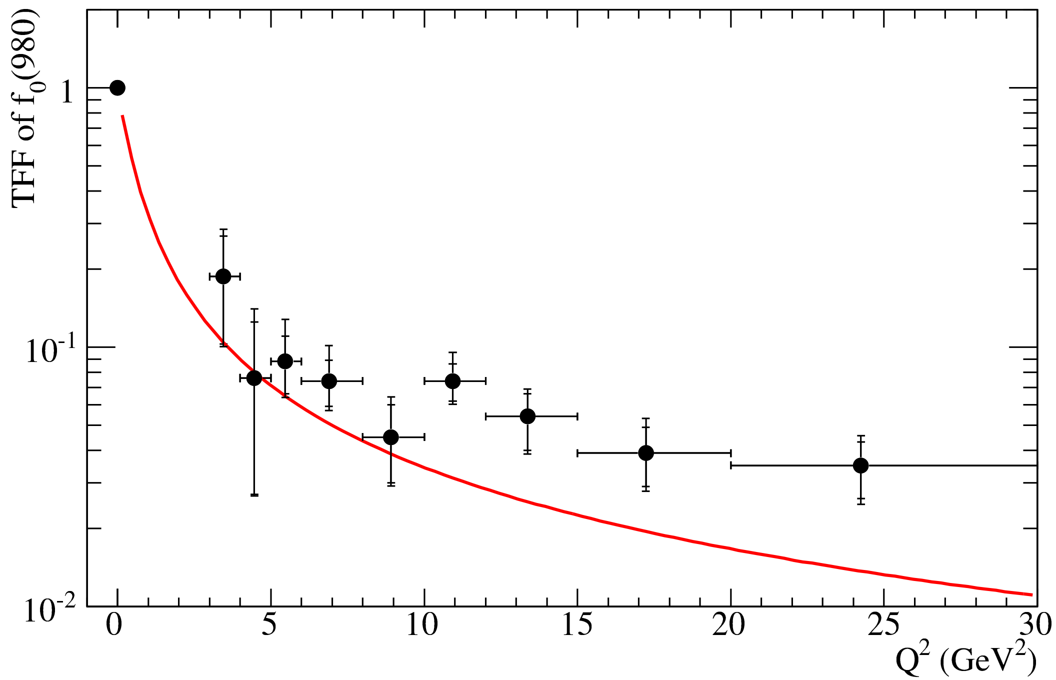


Belle data do not confirm fast rise observed at BaBar

B. Aubert et al. (BaBar Collab.), Phys. Rev. D 80, 052002 (2009),

S. Uehara et al. (Belle Collab.), Phys. Rev. D 86, 092007 (2012)

$\gamma\gamma^* \to \pi^0\pi^0$ at Belle – I

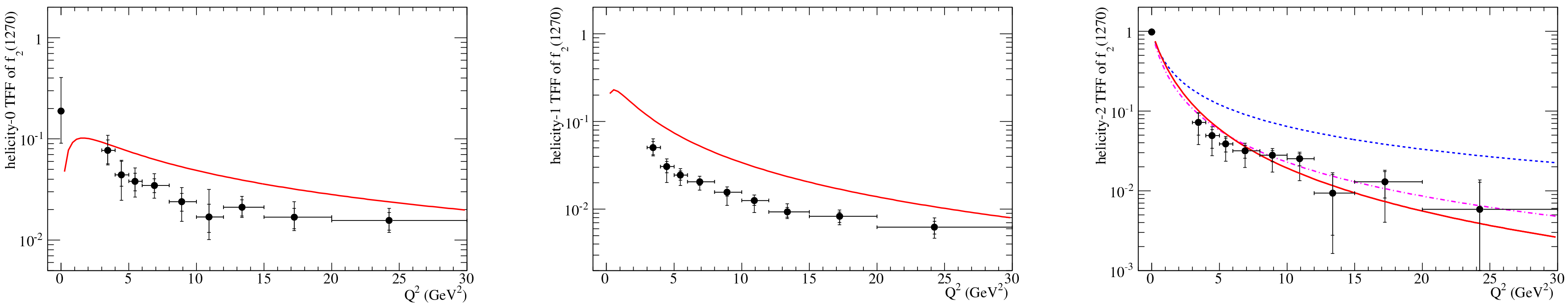


The $f_0(980)$ TFF agrees with the prediction up to 10 GeV^2,
but does not confirm steep fall at higher Q^2

Theory: G.A. Schuler et al., Nucl. Phys. B523, 423 (1998)

M. Masuda et al. (Belle Collab.), 1508.06757, Phys. Rev. D

$\gamma\gamma^* \to \pi^0\pi^0$ at Belle – II



The helicity-0 and -1 TFF of the $f_2(1270)$ are 1.5-2 times smaller than the prediction of [1], the helicity-2 is well described in [1] and [2]

Theory [1]: G.A. Schuler et al., Nucl. Phys. B523, 423 (1998),

Theory [2]: V. Pascalutsa et al., Phys. Rev. D85, 116001 (2012)

M. Masuda et al. (Belle Collab.), 1508.06757, Phys. Rev. D

Conclusions

- $e^+e^- \to e^+e^- +$ hadrons is easily studied at e^+e^- colliders
- $\gamma\gamma$ physics is quite rich: two-photon widths, spectroscopy of light-quark mesons, QCD tests, transition f/f in $\gamma\gamma^* \to R$, $J^{PC}(R) = 0^{-+},\ 0^{++},\ 1^{-+},\ 2^{++}$
- Resonance studies are very sensitive to interference with non-resonant continuum
- Various QCD tests for $\gamma\gamma \to \pi^+\pi^-,\ \pi^0\pi^0,\ \eta\pi^0,\ \eta\eta,\ K^+K^-,\ K_S^0K_S^0,\ p\bar{p}$
- Many results for various charmonia (discovery of $\chi_{c2}(2P)$)
- $\gamma\gamma$ physics is very promising for various QCD studies: resonance studies test various models (potential, tetraquark, molecule), energy and angular dependence of cross sections – pQCD
- Belle published 20 $\gamma\gamma$ papers with 1060 citations
- Further theoretical and experimental efforts needed

Backup slides

Parameters of $a_0(Y)$

Parameter	$a_0(Y)$	$a_0(1450)$
Mass, MeV	$1316.8^{+0.7+24.7}_{-1.0-\ 4.6}$	1474 ± 19
Width, MeV	$65.0^{+2.1+99.1}_{-5.4-32.0}$	265 ± 13
$\Gamma_{\gamma\gamma}\mathcal{B}(\eta\pi^0)$, eV	$432 \pm 6^{+1073}_{-\ \ 256}$	–