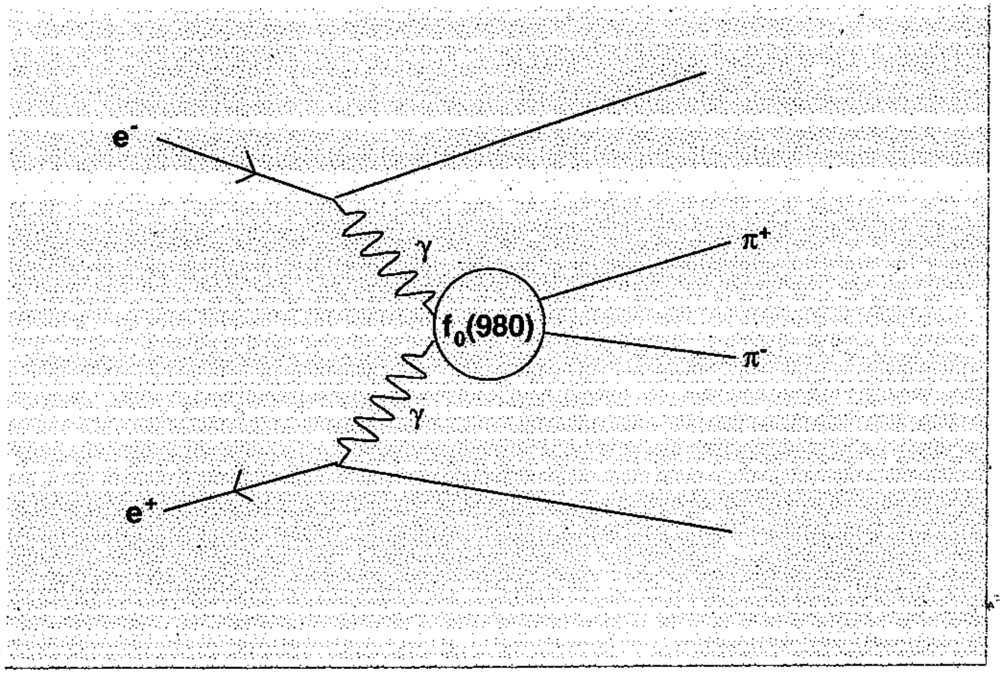
Observation of $f_0\,(980)$ resonance in two-photon collisions at Belle

T. Mori, Belle collaboration

February 25, 2003



Two-photon process

- New Resonances

$$\gamma\gamma \longrightarrow \text{resonance} \longrightarrow \begin{array}{c} \pi^+\pi^- \\ K^+K^- \\ K_sK_s \\ etc. \end{array}$$

- QCD

  Initial state is simple: $\gamma\gamma$

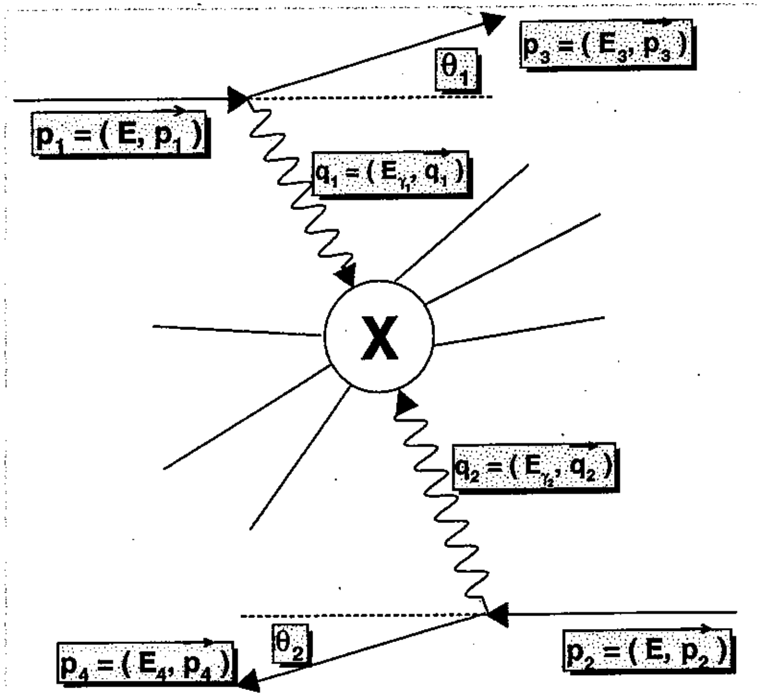
  Strong interactions are present only in final states.

  $\Downarrow$

  two-photon processes provide very clean tests of QCD.

- Glueball Anti-observation

Feature



- Photons emitted from e^+, e^- are mainly quasi real.
- Photons: $J^{PC} = 1^{--}$.
- Quasi real photons momenta are parallel to beam axis.
  $\Longrightarrow$ Good balance of transverse component of momenta p_t
- $J^{PC} = 0^{\pm +}, 2^{\pm +}$ resonances are mainly produced.

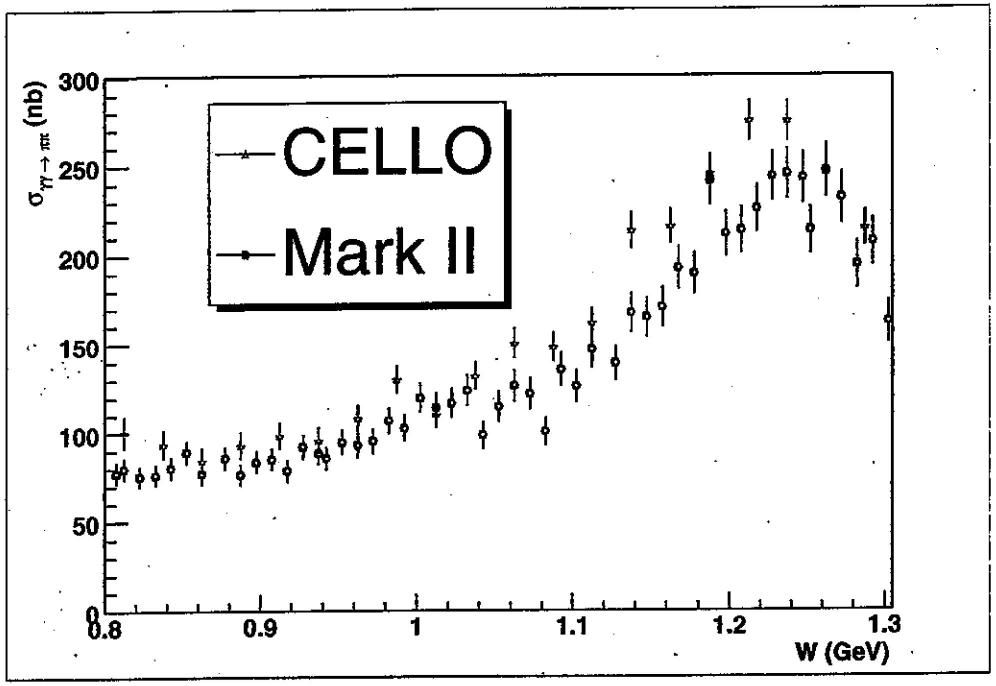
$\gamma\gamma \longrightarrow X \longrightarrow \pi^+\pi^-$

- $\pi^+\pi^-$ decay mode $\Longrightarrow$ G-Parity $G = +1$ $(G = (-1)^I C)$
- $J^{PC} = 0^{++}, 2^{++}$ resonances are mainly produced.

$\therefore$ In $\gamma\gamma \longrightarrow \pi^+\pi^-$ process, f_J $(J = \text{even})$ resonances can be observed.

- We can give an isospin information for resonances observed in the other decay modes. $\Longrightarrow$ f_J or not.
- $\Gamma_{\gamma\gamma} B$ (Resonance $\rightarrow \pi\pi$) can be measured.

$f_0\,(980)$ meson is not well understood.
This meson was recently observed in $D_s^+ \longrightarrow \pi^-\pi^+\pi^+$ decays.
The width $\Gamma_{\gamma\gamma}B\,(\mathrm{f}_0\,(980) \to \pi\pi)$ can be used to constrain the nature of the $f_0\,(980)$.

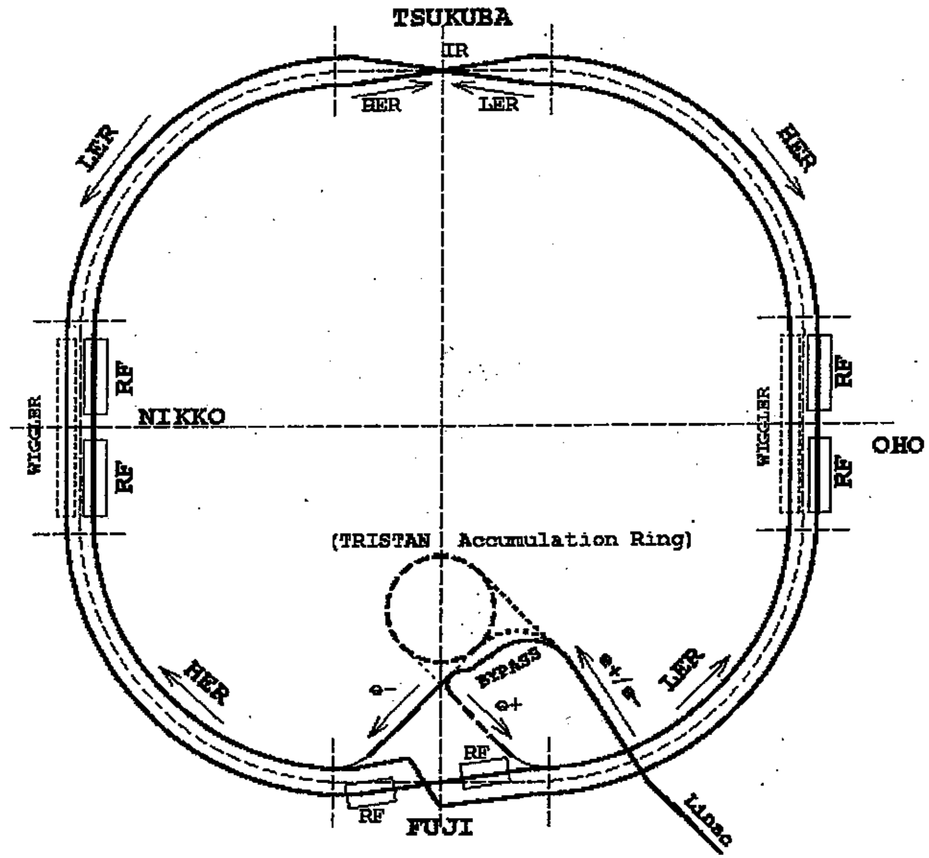


Eur. Phys. J. C9, 11-29 (1999)

The $f_0\,(980)$ was not seen clearly in previous two-photon experiments.

Belle Experiment

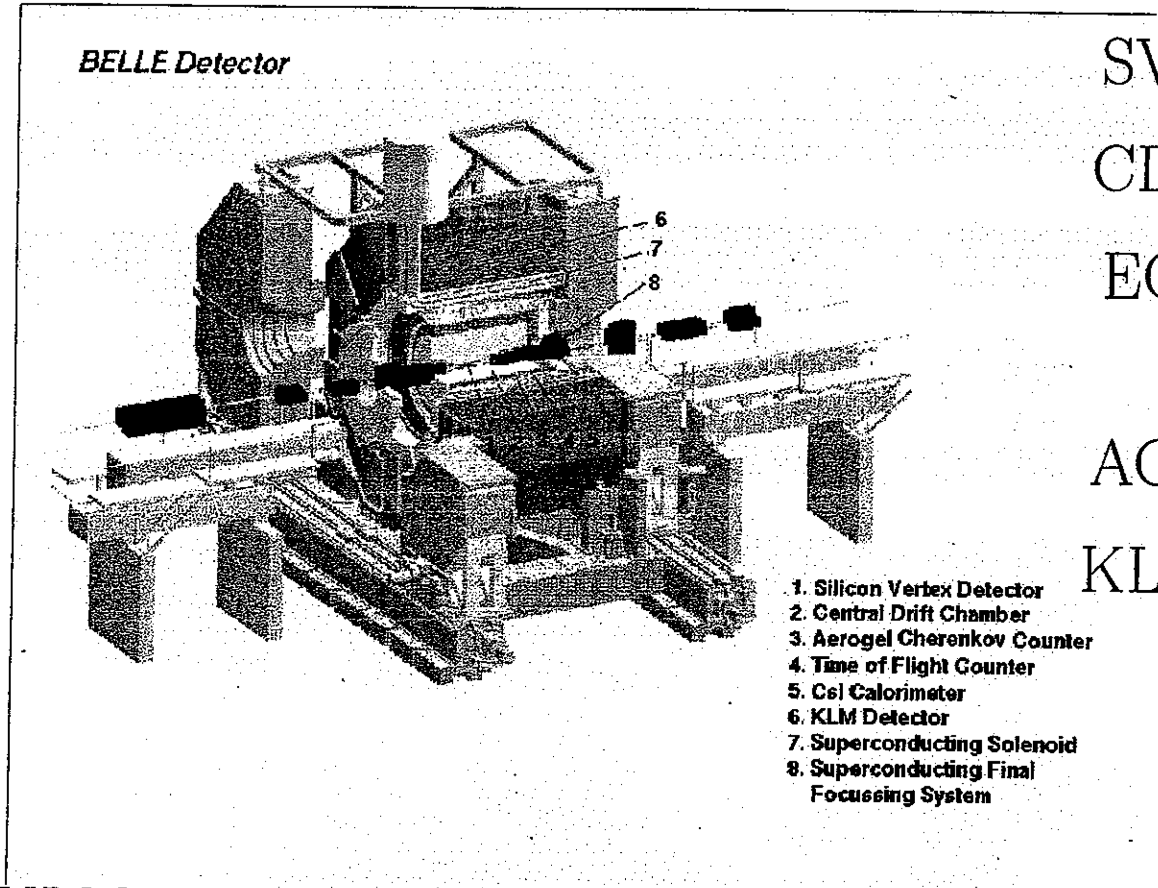
KEKB Accelerator



- 2 rings e^+-e^- collider
- 8.0GeV e^- and 3.5GeV e^+
- Maximum Luminosity Record: $L = 8.3 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

KEKB accelerator has very high luminosity. Useful for two-photon physics.

Belle Detector



Main Detectors

SVD: Silicon Vertex Detector

CDC: momenta measurement

ECL: CsI(Tl) energies of photons and electrons

ACC: K/π ID

KLM: μ/K_L ID

KLM is effective in the $W > 1.5$GeV mass region in $\gamma\gamma \longrightarrow \mu\mu$ process.

two-photon events

$$\gamma\gamma \longrightarrow \pi^+\pi^-$$
$$e^+e^-$$
$$\mu^+\mu^-$$
$$K^+K^-$$
$$\bar{p}p$$

$$p_t > 0.3\text{GeV/c}$$
$$|\Sigma p_t| < 0.1\text{GeV/c}$$
$$-0.47 < \cos\theta < 0.82$$

e^+e^- pairs are rejected by electron ID.

$$P_{e^+} < 0.66 \quad \& \quad P_{e^-} < 0.66$$

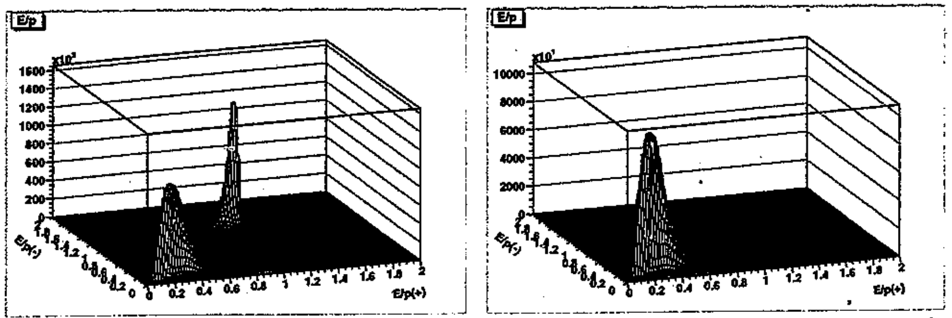


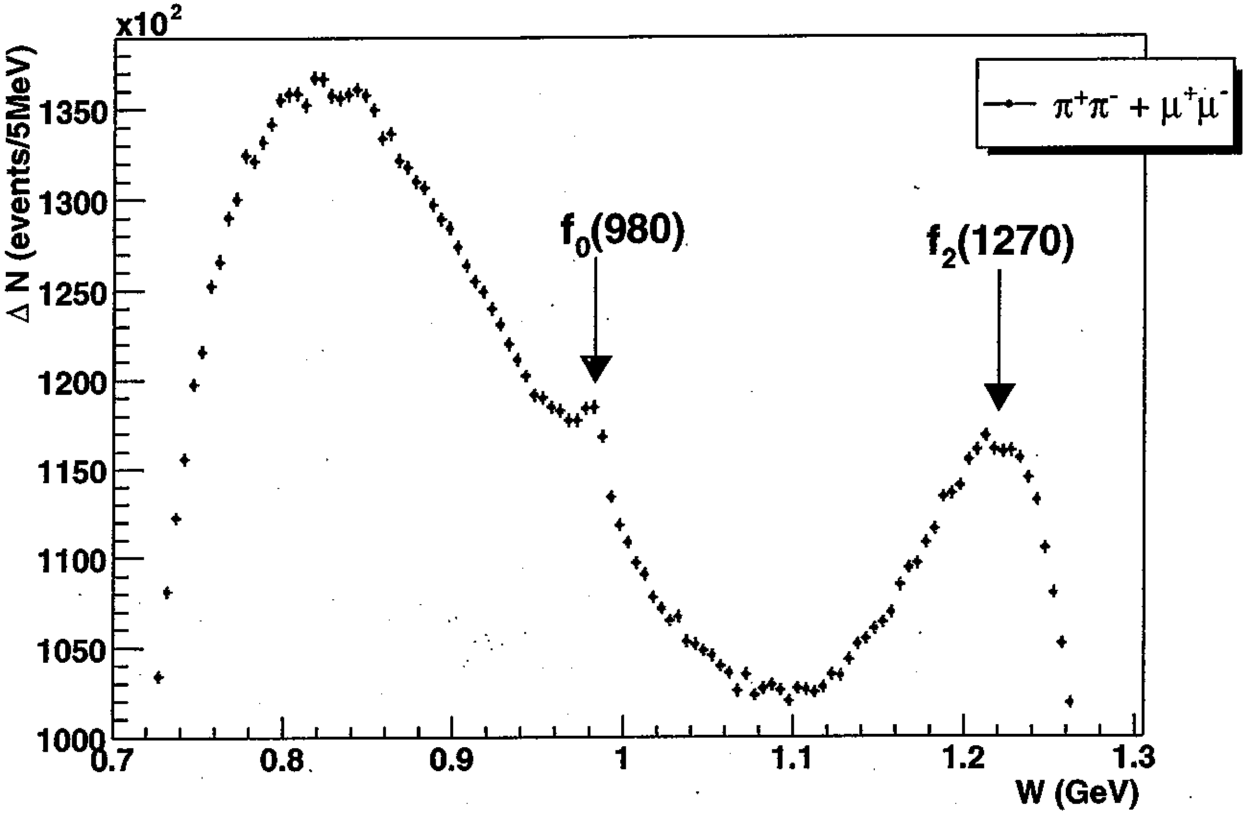
Figure 1: E/p scatter plot of before and after electron ID cut.

Particle ID devices:
TOF and dE/dx(CDC): $\pi/K/p$ separations
ACC: π/K separation at $p > 1.2$ (GeV)

Likelihood parametrized by Particle ID devices:

$$P\left(K^+;\pi^+\right) \times P\left(K^-;\pi^-\right) < 0.25$$
$$P\left(p;K^+\right) \times P\left(\bar{p};K^-\right) < 0.5$$

$\mu^+\mu^-$ pairs are not rejected.



$f_0(980)$ does not decay into $\mu^+\mu^-$.

$\mu^+\mu^-$ events are not rejected.

$|\cos\theta^*| < 0.6$

$$\gamma\gamma \longrightarrow e^+e^-, \; K^+K^-, \; \bar{p}p$$

events are rejected.

$$\gamma\gamma \longrightarrow \pi^+\pi^-, \; \mu^+\mu^-$$

events remain.

Mass Resolution

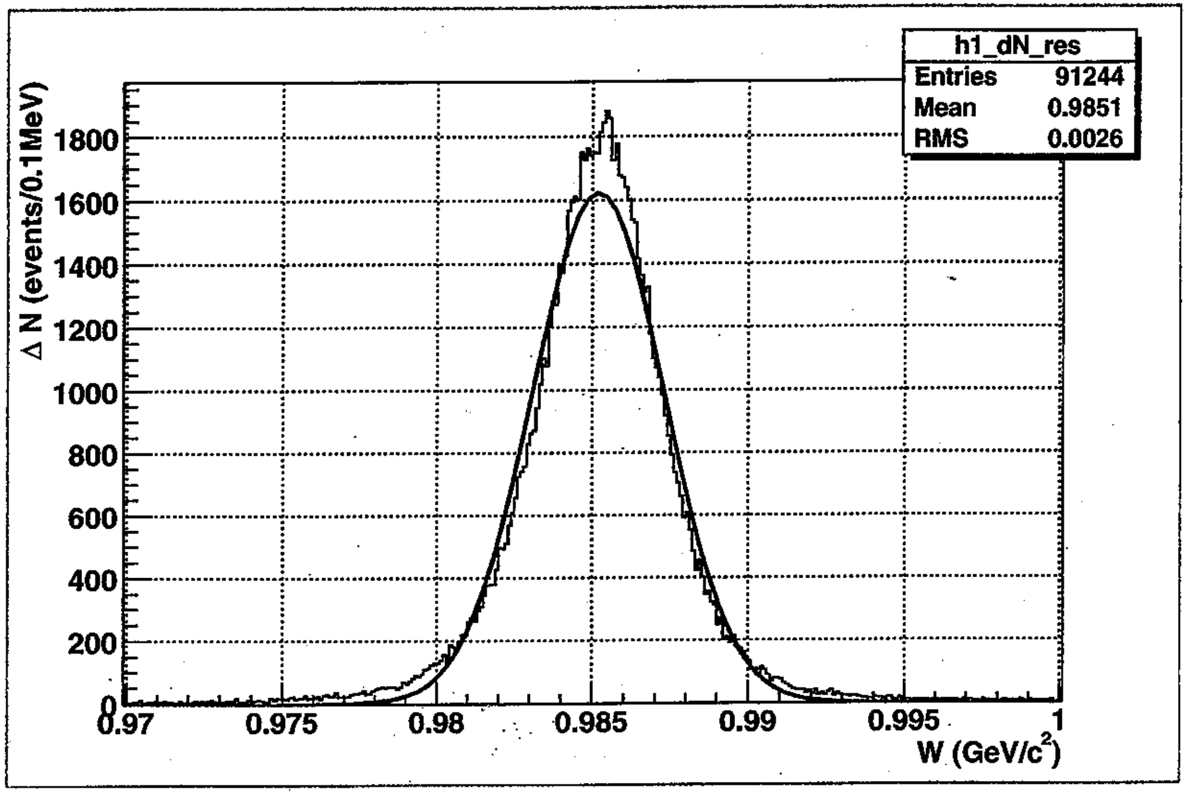


Figure 2: Mass Resolution of the Belle Detector.

MC simulation was used to obtain mass resolution. 1,000,000 $\pi^+\pi^-$events were generated at $W = 0.985$GeV.

$$| W - \overline{W} | < 1\,(\mathrm{MeV})$$

$$\sigma_M = 2\,(\mathrm{MeV})$$

Estimation of the number of $ee\pi^+\pi^-$ events

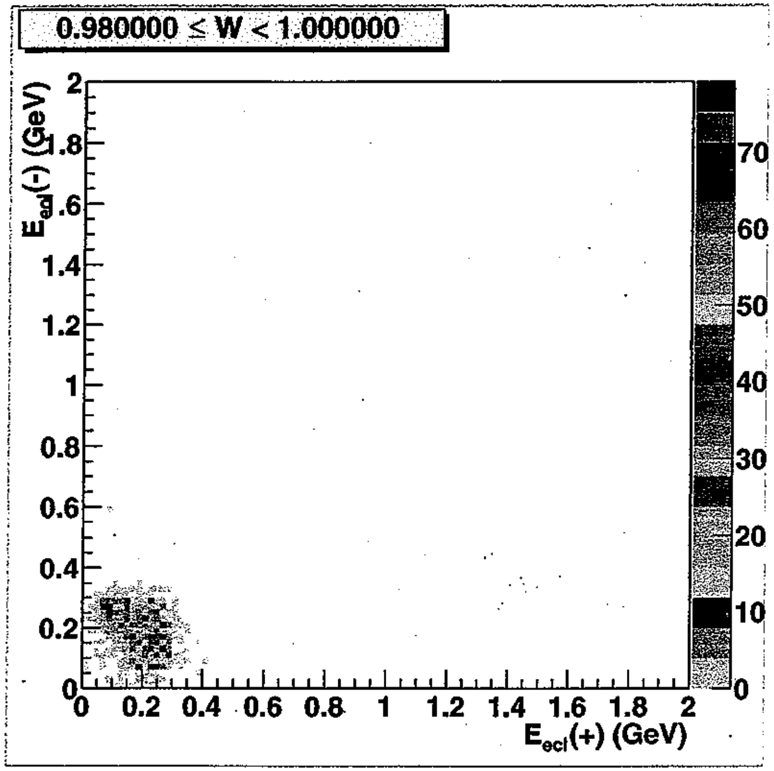


Figure 3: Scatter plot of energy deposit in the ECL(CsI(Tl)) detector. $ee \to ee\mu\mu$ MC was used.

Using the ratios of events in 4 regions:

1: $E_{\rm ecl}(+) < 0.35\,(\mathrm{GeV}) \cap E_{\rm ecl}(-) < 0.35\,(\mathrm{GeV})$

2: $E_{\rm ecl}(+) > 0.35\,(\mathrm{GeV}) \cap E_{\rm ecl}(-) < 0.35\,(\mathrm{GeV})$

3: $E_{\rm ecl}(+) < 0.35\,(\mathrm{GeV}) \cap E_{\rm ecl}(-) > 0.35\,(\mathrm{GeV})$

4: $E_{\rm ecl}(+) > 0.35\,(\mathrm{GeV}) \cap E_{\rm ecl}(-) > 0.35\,(\mathrm{GeV})$

Almost all events of $ee\mu\mu$ are in $E_{\rm ecl}(+) < 0.35\,(\mathrm{GeV}) \cap E_{\rm ecl}(-) < 0.35\,(\mathrm{GeV})$.

From ratio of number of events in each region, number of $ee\pi^+\pi^-$ events can be estimated.

Numbers of $ee\pi^+\pi^-$ and $ee\mu^+\mu^-$ events

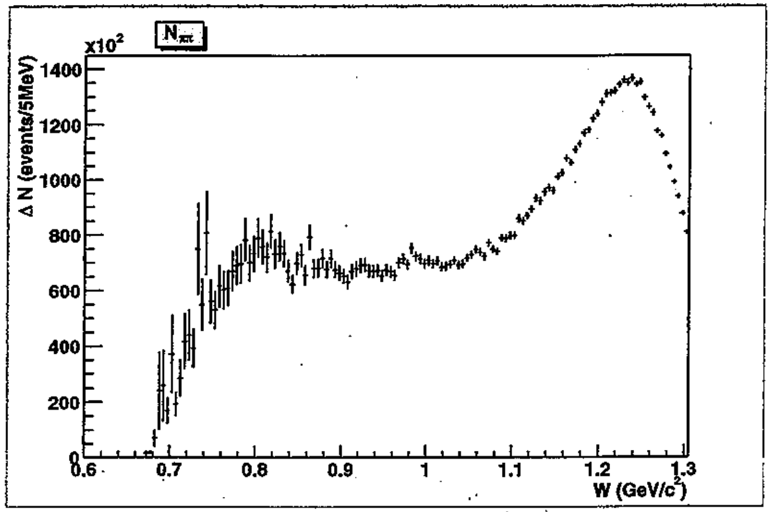


Figure 4: $ee\pi^+\pi^-$

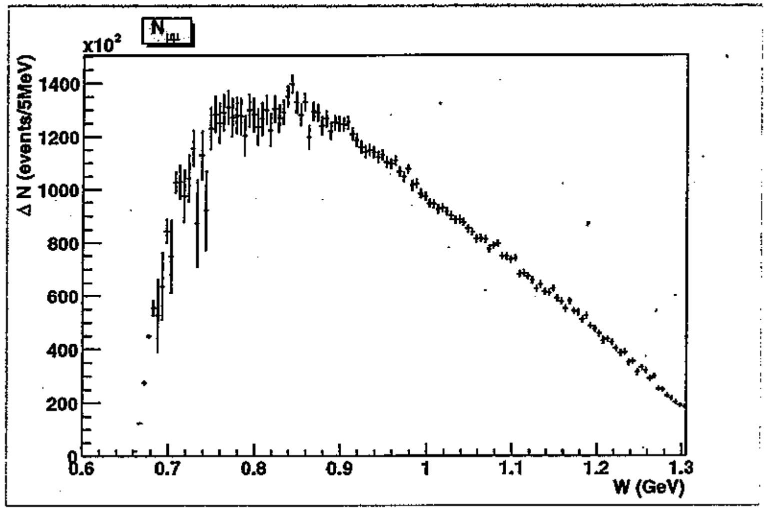
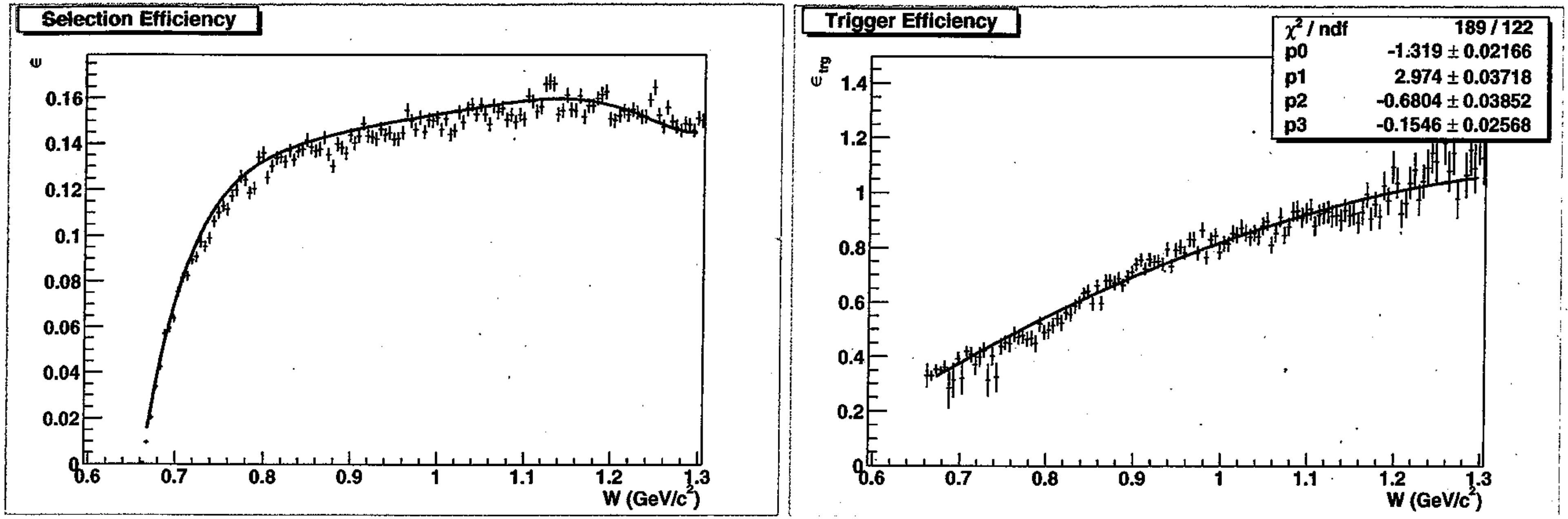
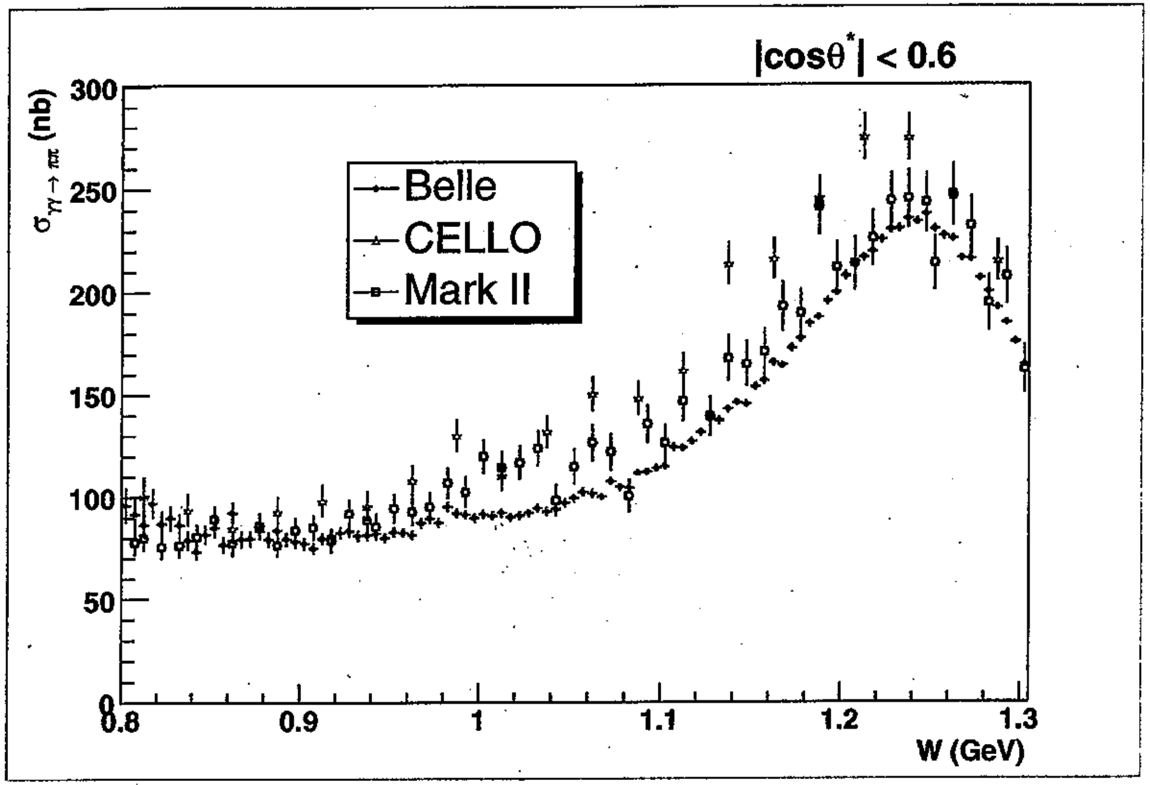


Figure 5: $ee\mu^+\mu^-$



Selection efficiency and trigger efficiency.
Selection efficiency is calculated from $\pi^+\pi^-$ MC simulation.
Trigger efficiency is calculated from $\mu^+\mu^-$ MC simulation.

Cross Sections of $\gamma\gamma \longrightarrow \pi^+\pi^-$



$\gamma\gamma \longrightarrow \pi^+\pi^-$ cross section with previous experiments.
Good consistency.

Fitting for $f_0\,(980)$

$$\Delta N_{f_0} = \sigma \cdot \epsilon \cdot \epsilon_{\rm trg} \cdot \frac{\mathrm{d}L_{\gamma\gamma}}{\mathrm{d}W} \cdot \Delta W \cdot \int L\mathrm{d}t$$

$$\sigma = \frac{S \cdot \Gamma}{\left(W^2 - M^2\right)^2 + M^2 \cdot \Gamma^2}$$

$$\Delta N_{\rm BG} = C_0 + C_1 W + C_2 W^2$$

σ: cross section of $\gamma\gamma \longrightarrow f_0\,(980) \longrightarrow \pi^+\pi^-$

ϵ: detection efficiency

$\epsilon_{\rm trg}$: trigger efficiency

$\frac{\mathrm{d}L_{\gamma\gamma}}{\mathrm{d}W}$: Luminosity function

$\int L\mathrm{d}t$: integrated luminosity

S: $S = \sigma M^2 \Gamma$

M: mass of $f_0\,(980)$

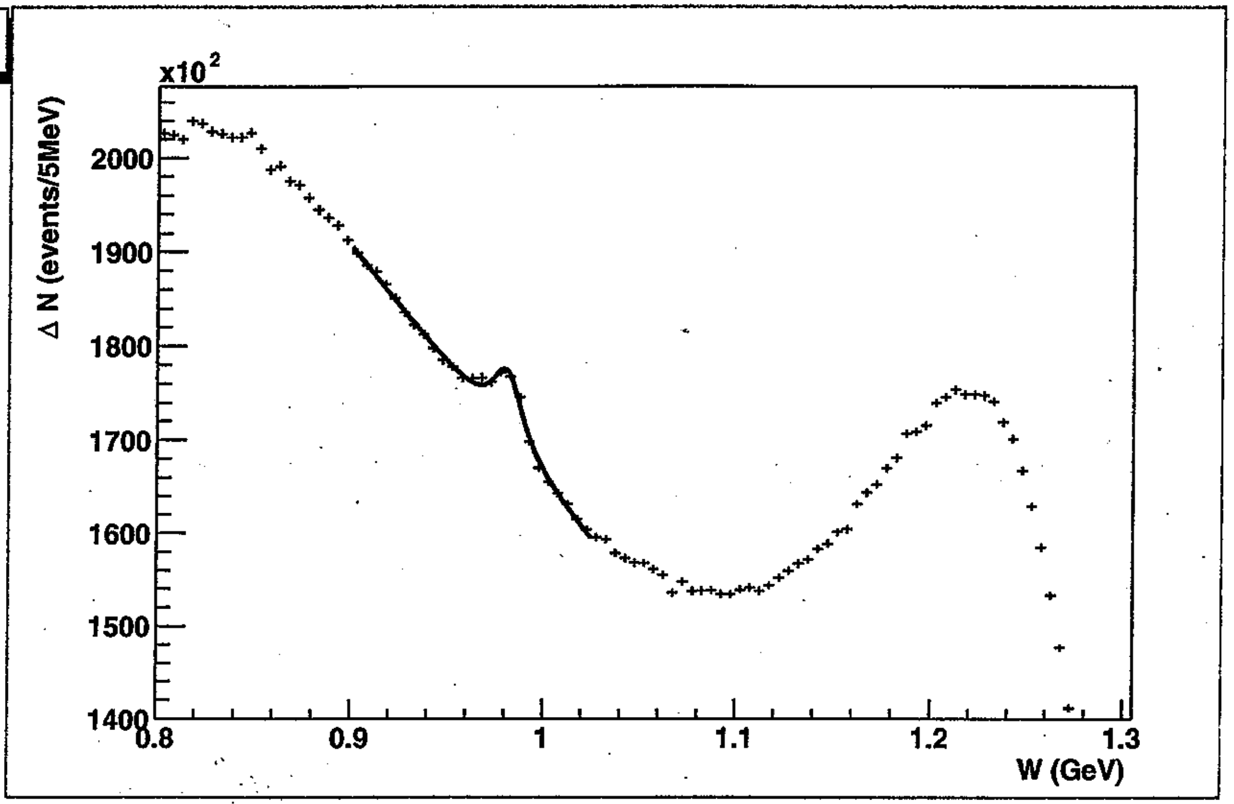
Γ: width of $f_0\,(980)$

fit function: $\Delta N = \Delta N_{f_0} + \Delta N_{\rm BG}$

Interference term was not considered.

fit parameters: C_0, C_1, C_2, S, M, Γ

Fit Result



- $\int L dt = 88.9 \mathrm{fb}^{-1}$
- $|\cos\theta^*| < 0.6$
- $\frac{\chi^2}{n} = \frac{22.25}{19} \cong 1.17$

resonance	$f_0(980)$
M(MeV)	981.3 ± 0.4
Γ(MeV)	19.7 ± 1.6

Only statistical errors are shown. Systematic errors are now under study.

$$\Gamma_{\gamma\gamma}\left(f_0\left(980\right)\right) B\left(f_0\left(980\right) \to \pi^+\pi^-\right) = \frac{\sigma M^2 \Gamma}{8\pi\left(2J+1\right)F}$$

$$= \frac{S}{8\pi\left(2J+1\right)F}$$

$$F = \left(2J+1\right) \sum_{\lambda=0,2} f_\lambda \int_0^{0.6} \left[d^J_{\lambda 0}\left(z\right)\right]^2 \mathrm{d}z$$

$$F = 0.6 \quad \left(J=0\right)$$

Summary

The Belle's result on $\Gamma_{\gamma\gamma}\left(f_0\left(980\right)\right) B\left(f_0\left(980\right) \to \pi\pi\right)$ will be shown after systematic errors study finished.
The result seems to be much smaller than the PDG value which is $\Gamma_{\gamma\gamma}\left(f_0\left(980\right)\right) = 0.39^{+0.10}_{-0.13}$ (keV).
$f_0\left(980\right)$ was seen as a positive peak with a narrower width than one given by PDG.