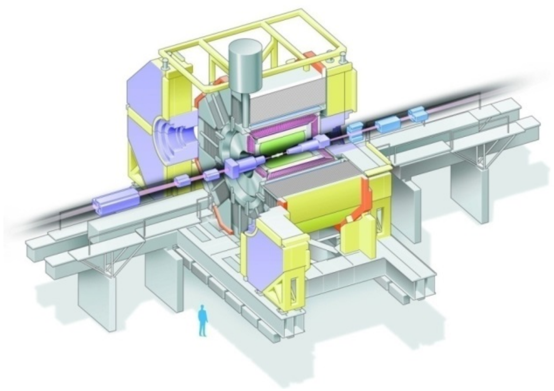
Gamma gamma physics at Belle



Z. Q. Liu (劉 智青)

On behalf of Belle Collaboration

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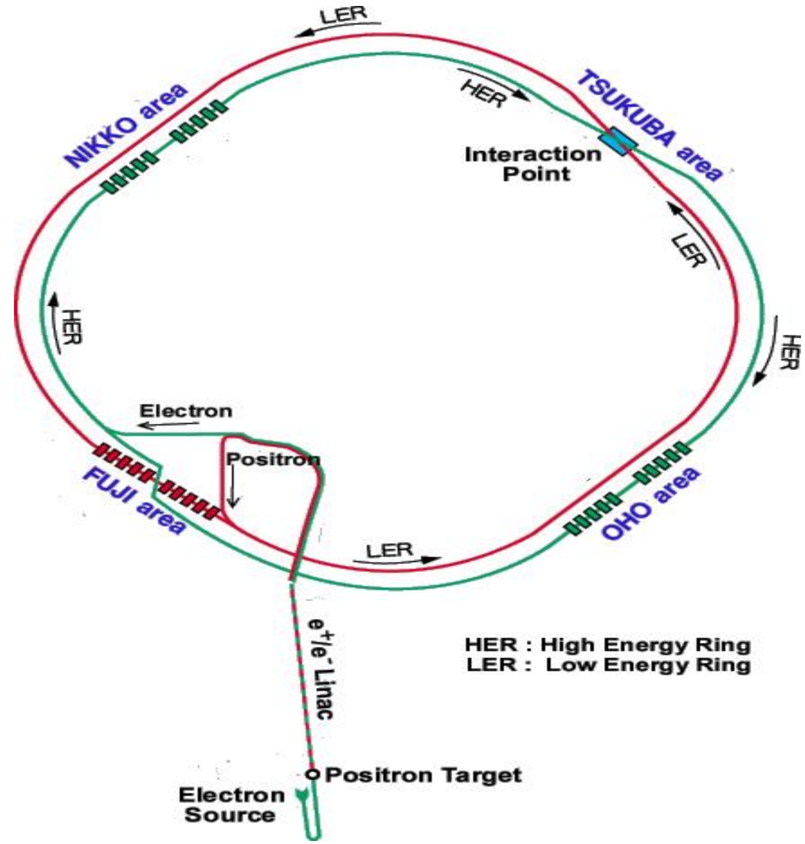
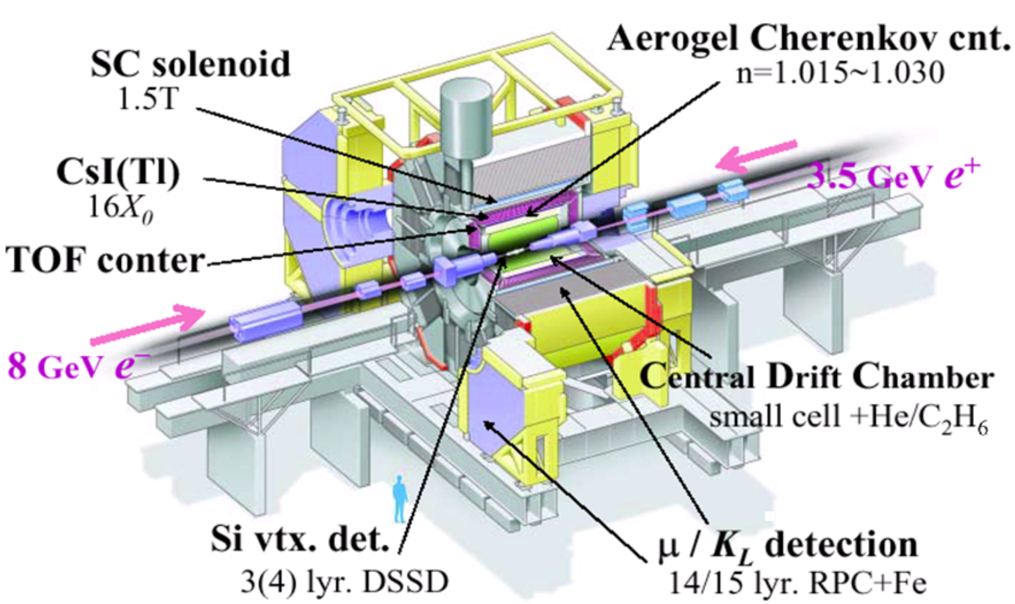
$(g\text{-}2)_{\mu}$: Quo vadis, 9th April, Mainz

KEKB and Belle

- Asymmetric $e^+ e^-$ collider
  8 GeV e^- (HER) x 3.5 GeV e^+ (LER)
  $\sqrt{s}$=10.58 GeV ⇔ $\Upsilon(4S)$
  Beam crossing angle: 22mrad
- Continuous injection
- Luminosity
  L_{max}=2.1x10^{34} cm^{-2}s^{-1}
  World record !





High momentum/energy resolutions
CDC+Solenoid, CsI

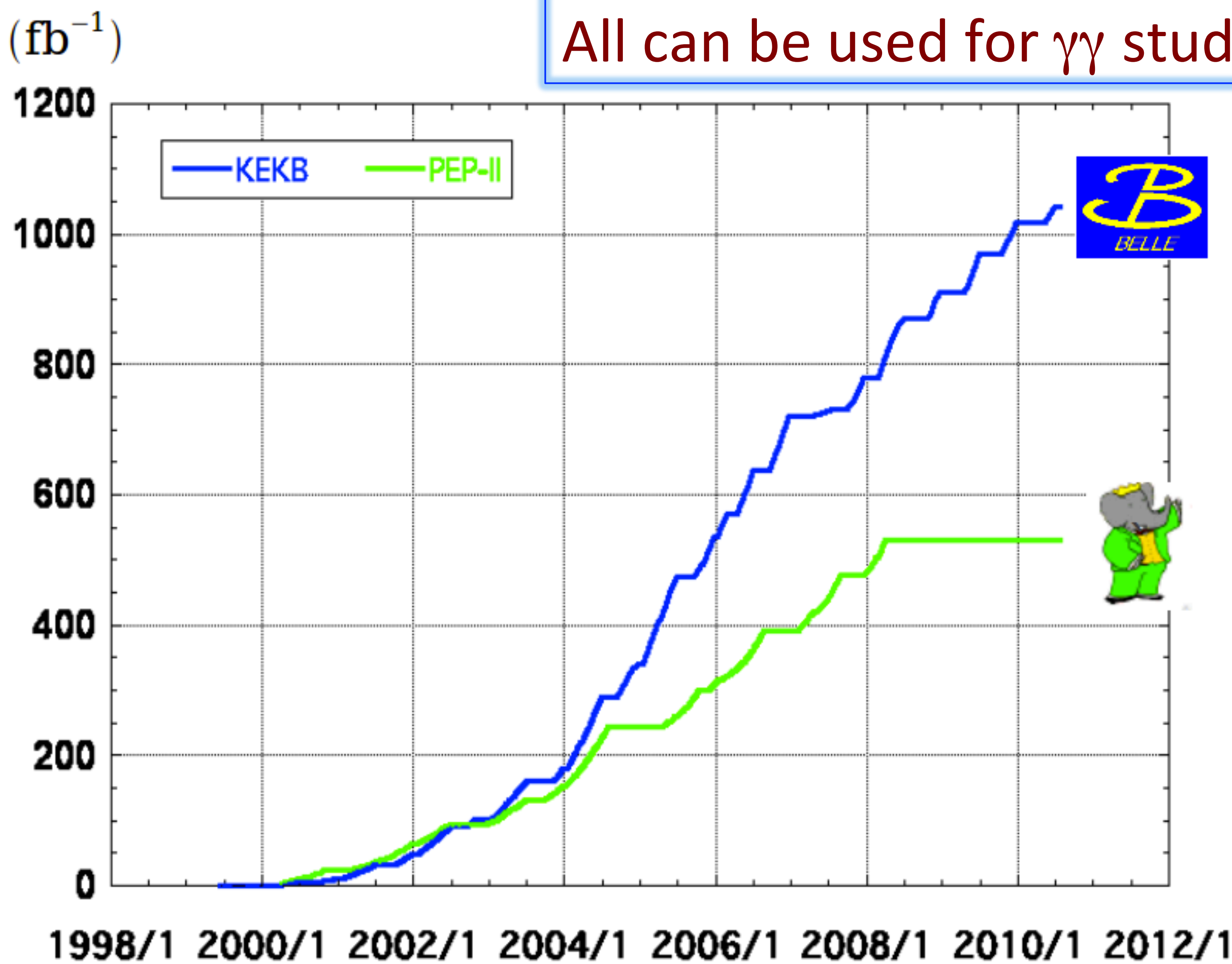
Vertex measurement – Si strips

Particle identification
TOF, Si-aerogel, CDC-dE/dx,
RPC for K_L/muon

Running >10 years

Integrated luminosity of B factories

All can be used for γγ study !



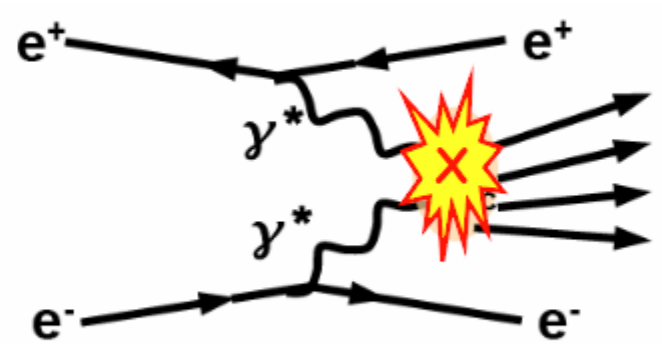
> 1 ab^{-1}

On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

~ 550 fb^{-1}

On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Hadron/QCD physics



$\gamma^*\gamma^*$ interaction in an e^+e^- Collider

1. Quasi-real photons: both γ^* have small Q^2, $Q^2 << W^2_{\gamma\gamma}$, $Q^2 << E^2_{QCD}$, non-tag method, characteristic $|\Sigma Pt^*|$ distribution.

- Hunt new hadrons, study hadron structure, test pQCD…

$\Gamma_{\gamma\gamma}$*Br($\gamma\gamma \to$ f) or $\gamma\gamma \to$ f cross section, $\gamma\gamma$ coupling constant, provide info. of hadron structure.

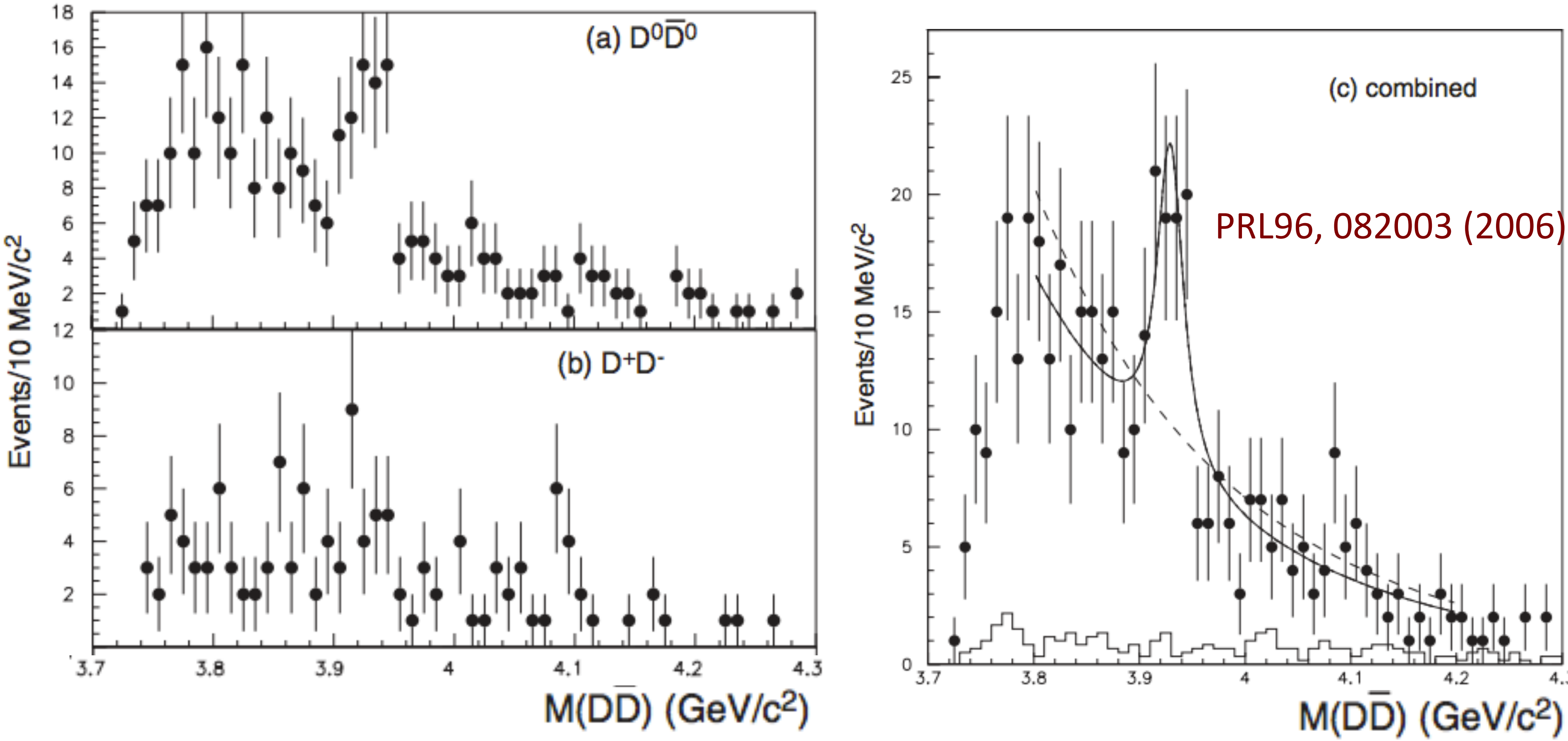
Quantum number constraint: Q=0, C=+, $J^P=0^+, 0^-, 2^+, 2^-$ …

2. High virtuality: large Q^2, double-tag ($\gamma^*\gamma^*$) or single-tag method (γ^*).

- Form factor measurement: π^0
- Test pQCD…

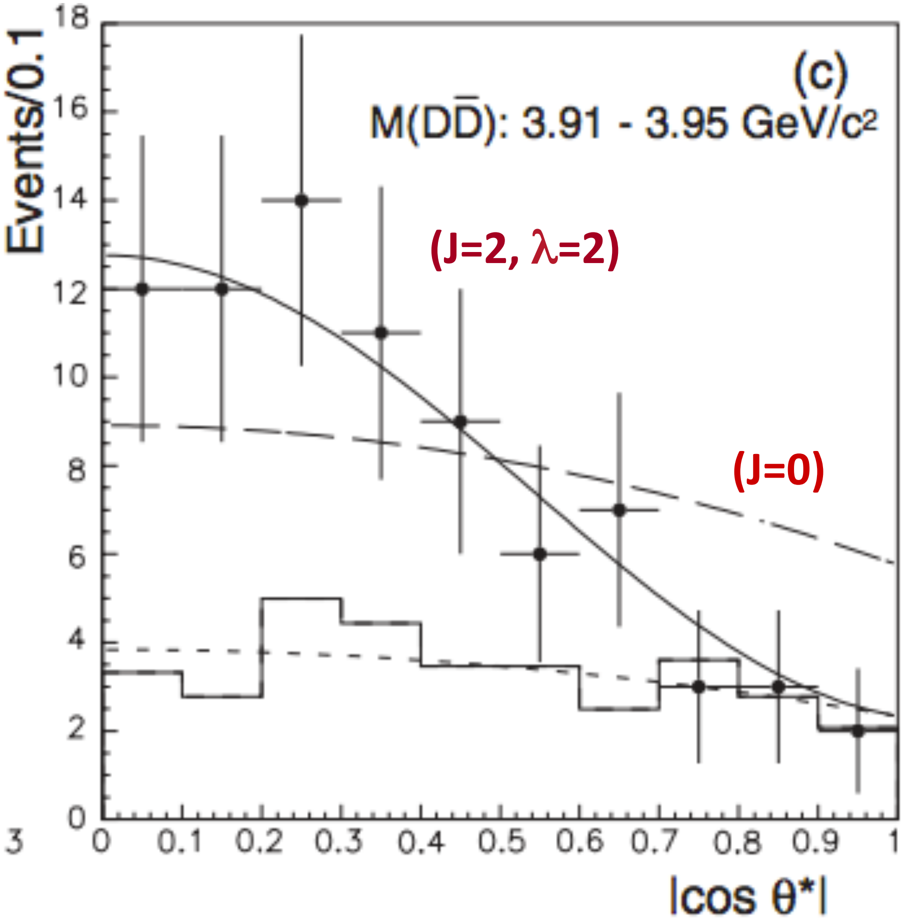
Hadron physics with quasi-real photons

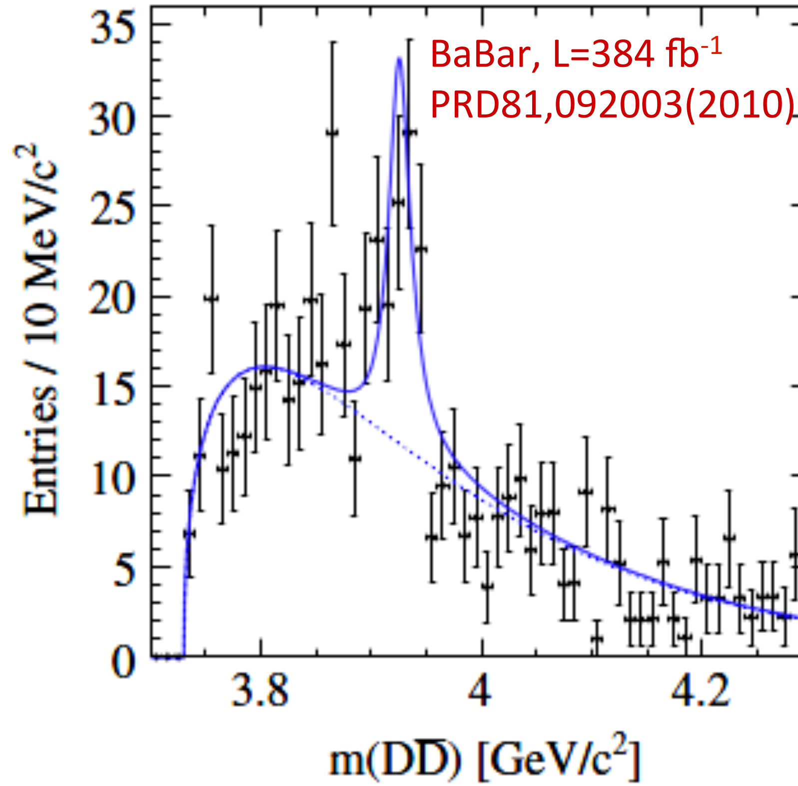
Observation of $\chi_{c2}(2P)$



1. Potential model: M[χ_{c2}(2P)]~3.9-4.0 GeV, decay to DD, $J^{PC}=2^{++}$
2. Lum=395 fb^{-1} @ Belle, $\gamma\gamma \rightarrow$DD process
3. M(Z(3930)) = 3929 ± 5 ± 2 MeV/c^2; Γ(Z(3930))= 29 ± 10 ± 2 MeV;
   $\Gamma_{\gamma\gamma}$*Br(Z(3930)$\rightarrow$DD)=0.18 ±0.05 ±0.03 keV

Observation of $\chi_{c2}(2P)$





Confirmed by BaBar, mass & width agree with Belle

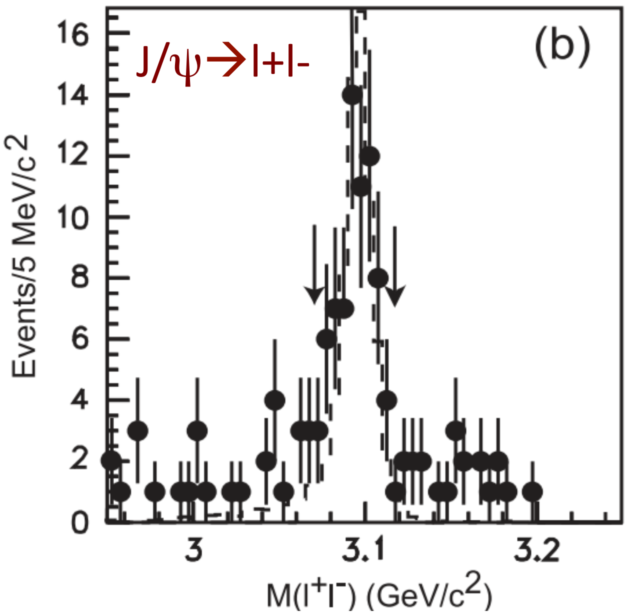
1. Scatter angle distribution of final D meson; favor Spin-2 option
2. It should be the $\chi_{c2}(2P)$

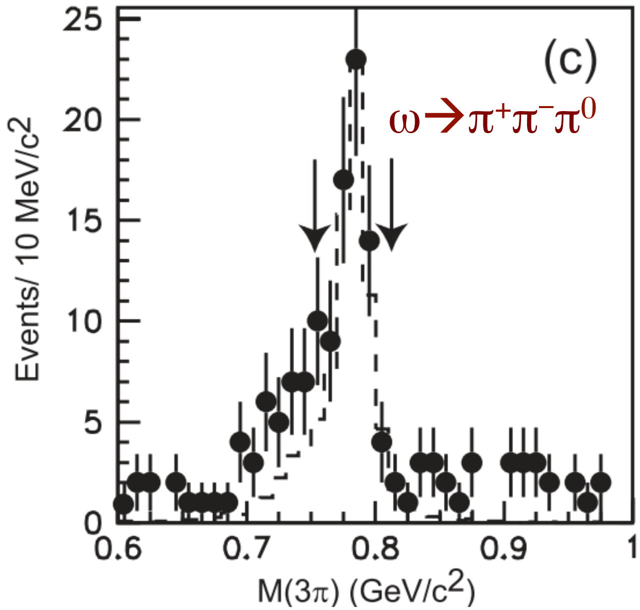
$\chi_{c2}(2P)$ $\quad I^G(J^{PC}) = 0^+(2^{++})$

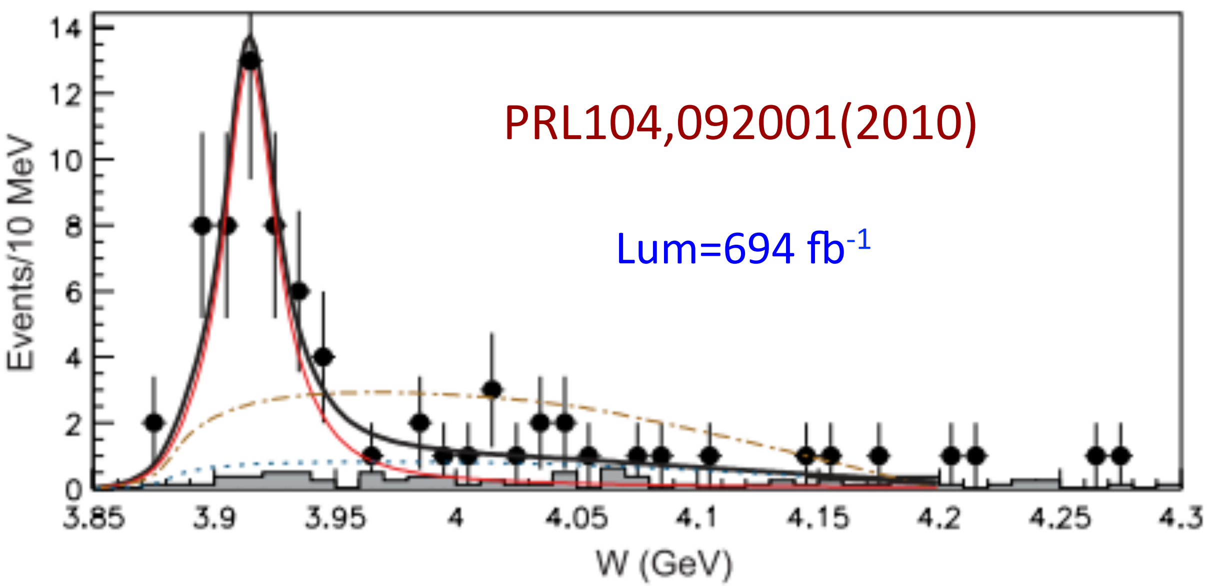
Mass $m = 3927.2 \pm 2.6$ MeV
Full width $\Gamma = 24 \pm 6$ MeV

PDG 2011

$\chi_{c0}(2P)$ candidate

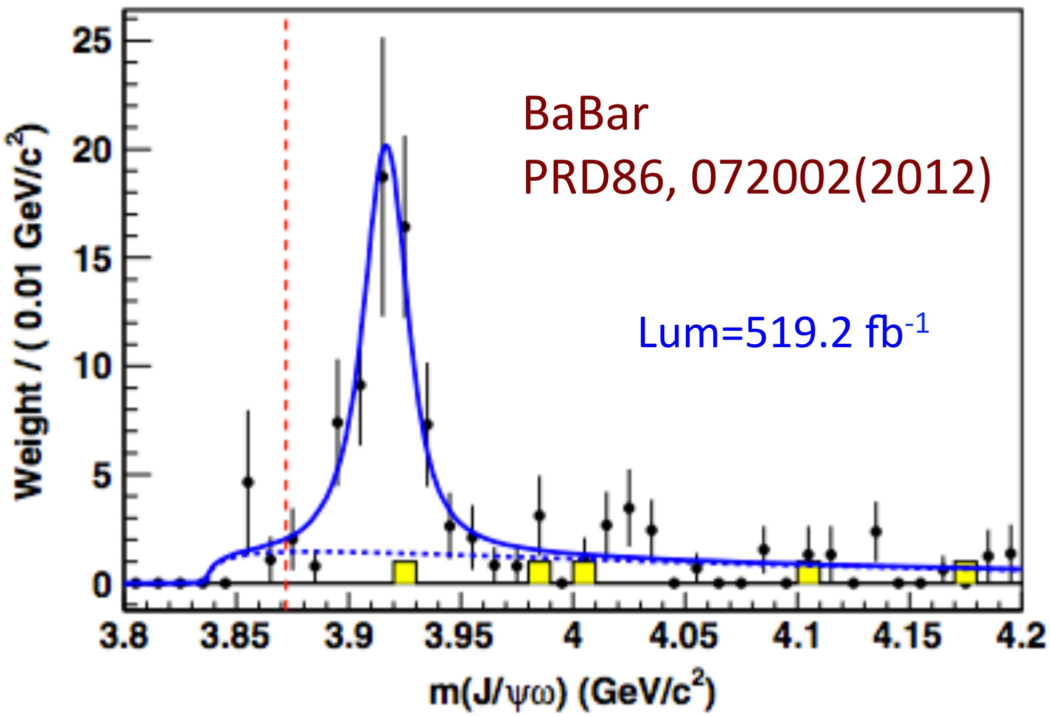


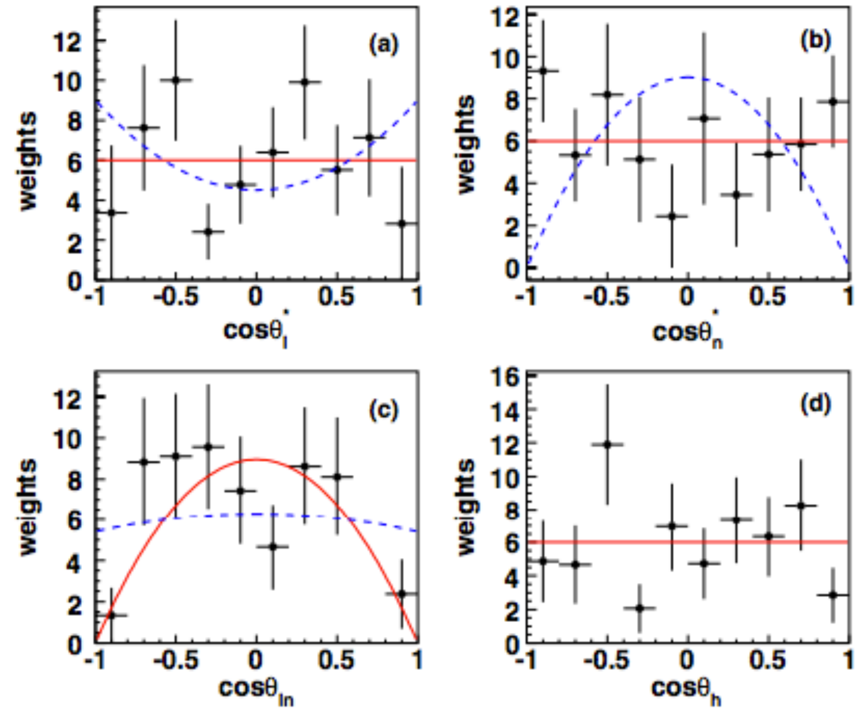




1. Belle $\gamma\gamma \rightarrow \omega J/\psi$ process using "zero-tag" events.
2. Observe a structure near 3.9 GeV, X(3915) significance 7.7σ
3. Mass=(3915±3±2) MeV, width=(17±10±3) MeV
4. Candidate for $\chi_{c0}(2P)$

$\chi_{c0}(2P)$ candidate





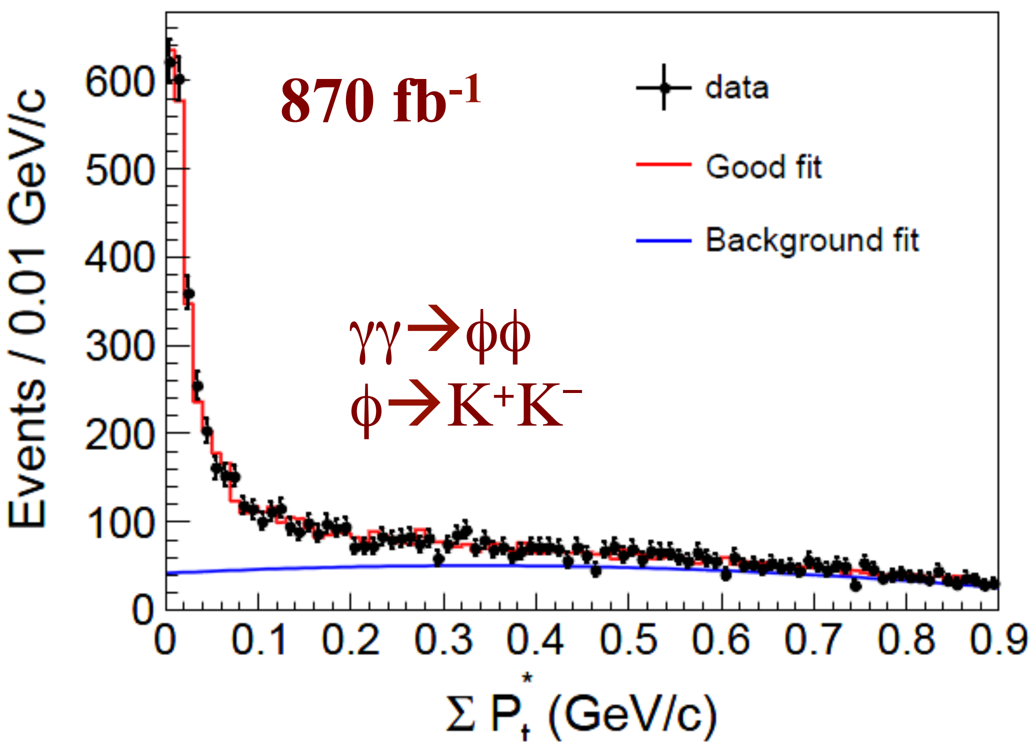
1. Confirmed by BaBar: M=3919.4±2.2±1.6 MeV; Width=(13±6±3) MeV
2. Further angular analysis supports $J^{PC}=0^{++}$
3. Belle: $\Gamma_{\gamma\gamma}$*Br(X(3915)→$\omega J/\psi$)=(61±17±8) eV; BaBar=(52±10±3) eV
4. If one assume $\Gamma_{\gamma\gamma}$<keV, Br[X(3915)→$\omega J/\psi$]~(1-6)%

$\chi_{c0}(2P)$ was $X(3915)$

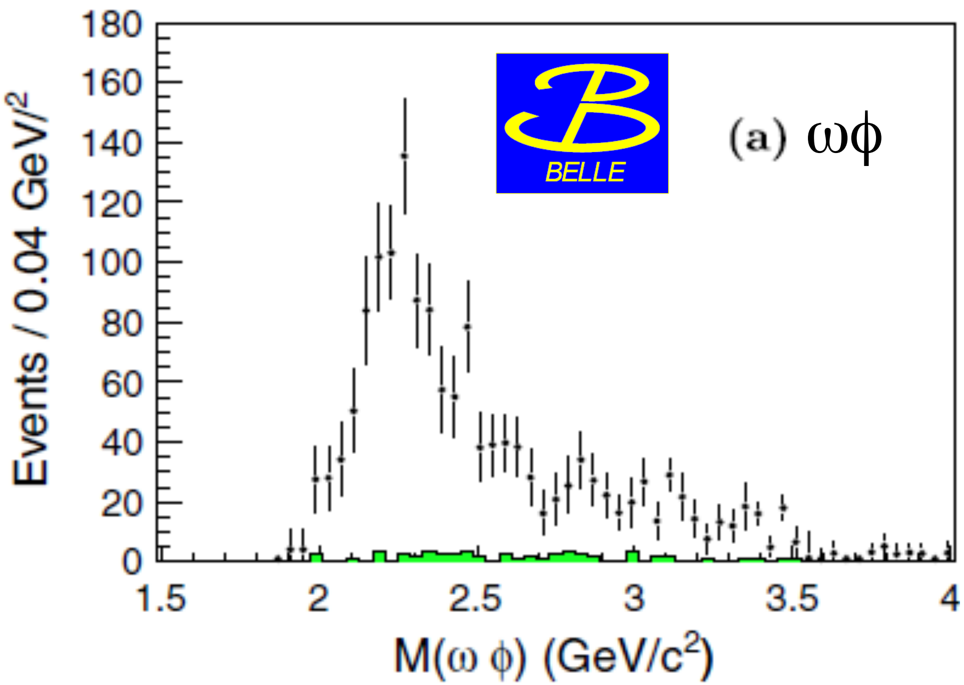
$I^G(J^{PC}) = 0^+(0^{++})$

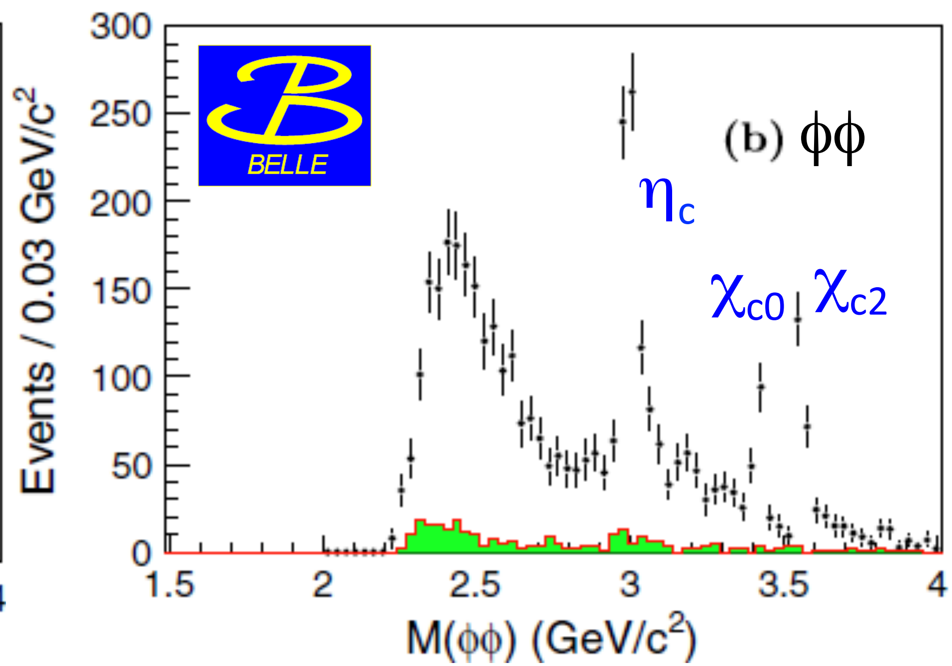
$\gamma\gamma \rightarrow \omega\phi$, $\phi\phi$, $\omega\omega$

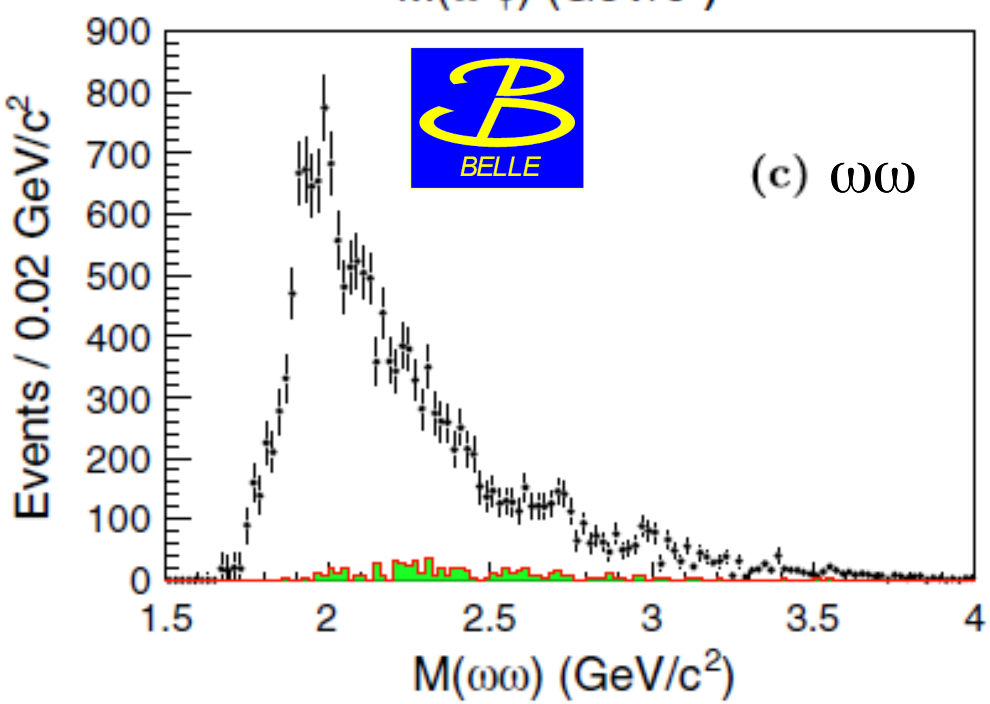
- $\gamma\gamma \rightarrow VV$: "golden" channel → 4-quark hadron
- VV pair well "glued" to $\gamma\gamma$ system,
- Models: MIT bag… (Sov. Phys. Usp. 34,1991)
- exmaple: $\gamma\gamma \rightarrow \rho^+\rho^-, \rho^0\rho^0, K^{*+}K^{*-}$…(L3 & ARGUS)
- Enhancements near $\rho^0\rho^0$ threshold, but not $\rho^+\rho^-$?



1. Un-tag method
2. Signal events: $|\Sigma Pt^*|$ (vector sum) ~ 0
3. Fit $|\Sigma Pt^*|$ distribution → signal events yield
4. Background estimated through ω/ϕ sideband

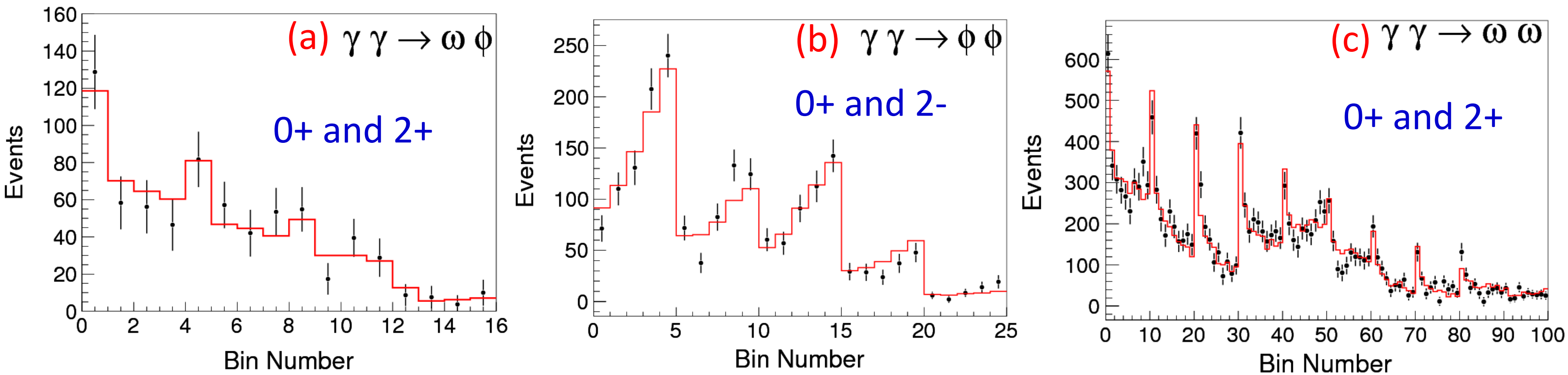






1. (a) $\omega\phi$ (b) $\phi\phi$ (c) $\omega\omega$ mass spectrum in two-photon process.
2. Background is estimated from sideband, i.e. 4K, 6π…
3. Obvious enhancement below 2.8GeV/c^2
4. Charmonia is observed significantly in $\phi\phi$ mode.

Spin-Parity results for M(VV)<2.8GeV/c^2



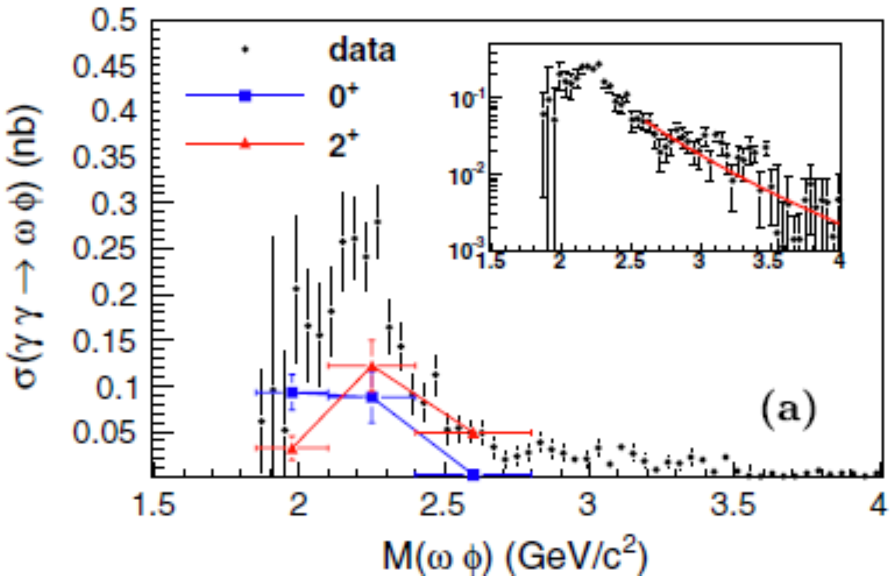
Angle definition:

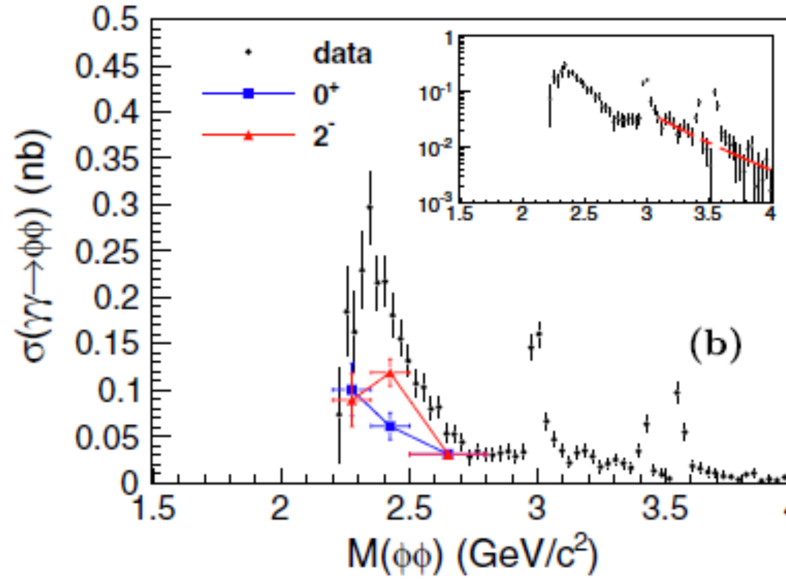
1. Five kinematically independent angles: $\cos\theta$, $\cos\theta^*$, $\cos\theta^{**}$, ϕ^*, ϕ^{**}
2. Transversity angle: $\phi_T=|\phi^*+\phi^{**}|$; Polar-angle product: $\Pi_\theta=(\sin\theta^*)^2\times(\sin\theta^{**})^2$
3. (a)4×4 (b)5×5 (c)10×10 bins. Fig (a) shows Π_θ distribution in each ϕ_T bin, i.e. Π_θ distribution while $\phi_T \in$ [0.0.25) for first 4 bins and similarity for others.
4. Fit 2-D angle distribution f(ϕ_T, Π_θ) to extract different J^P components.

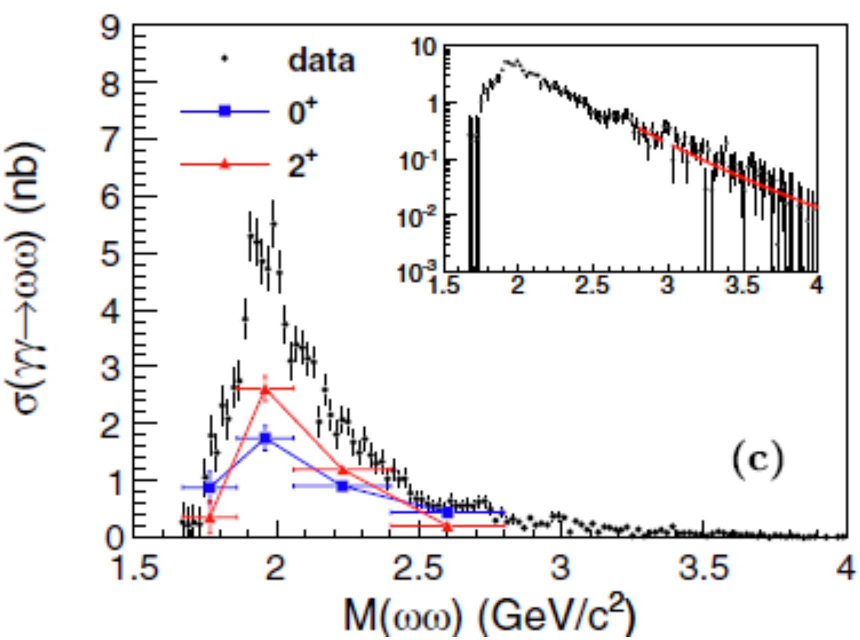
(a). 0^+ S-Wave or 2^+ S-Wave

(b). 0^+ S-Wave and 2^- P-Wave (c). 0^+ S-Wave and 2^+ S-Wave

Cross section measurement







1. (a) ωϕ (b) ϕϕ (c) ωω cross section together with different J^P component contribution.

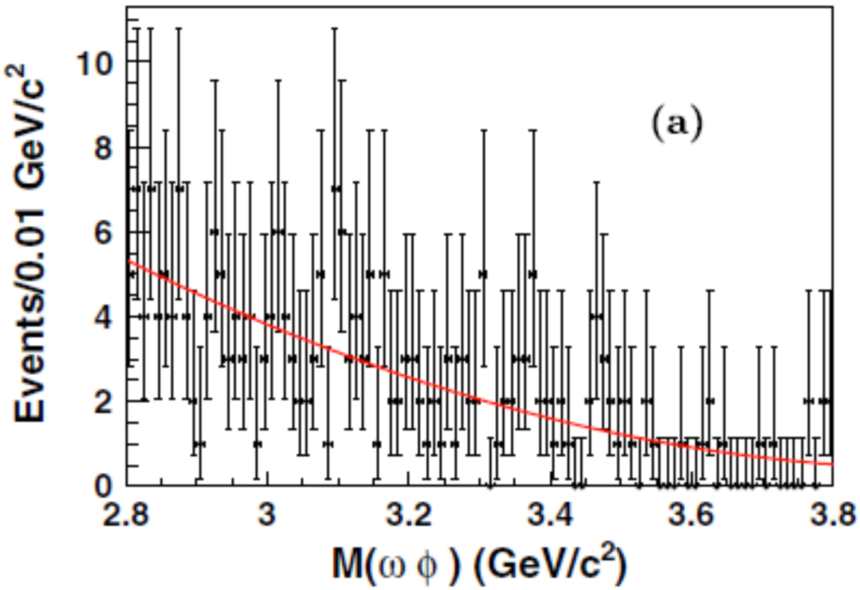
2. Efficiency is got through MC simulation and re-weighed according to mass dependent spin-parity analysis result.

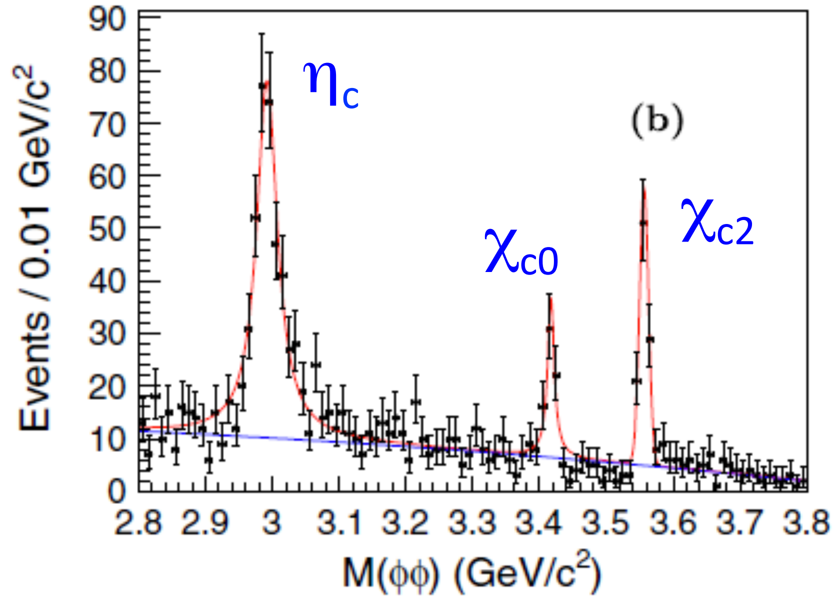
3. Sys. error would be (a)15% (b)11% (c)13%

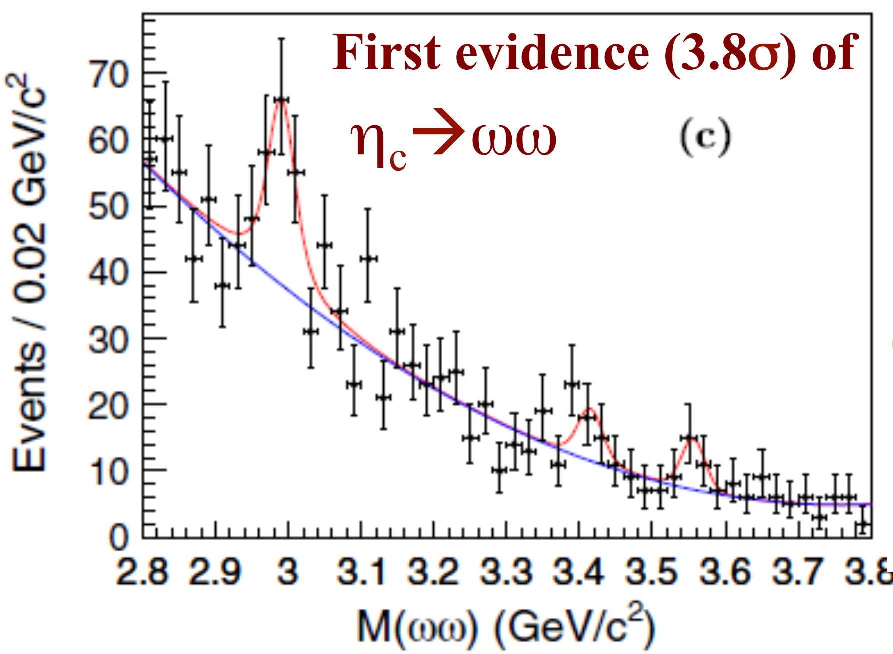
4. Power law (W^{-n}) fit for high energy region:

n=7.2±0.6(a), 8.4±1.1(b), 9.1±0.6(c).

Charmonium results







1. Clear η_c, χ_{c0} and χ_{c2} signal in (b)$\phi\phi$ mode and first evidence for (c)$\eta_c \rightarrow \omega\omega$.
2. Measurement of $\Gamma_{\gamma\gamma}$*Br(VV)

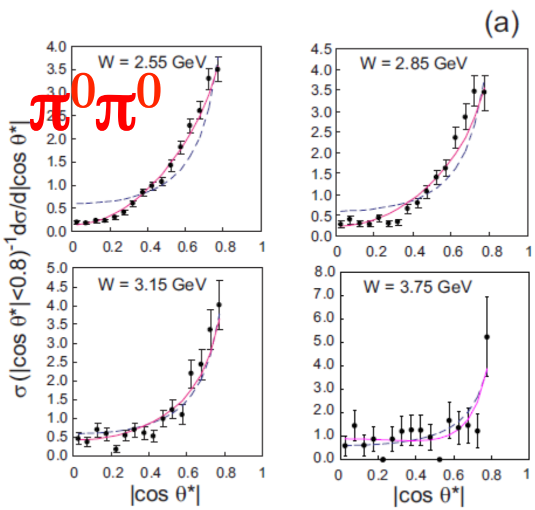
TABLE II: Results of $\Gamma_{\gamma\gamma}\mathcal{B}(X \to VV)$ (eV) for η_c, χ_{c0} and χ_{c2}.

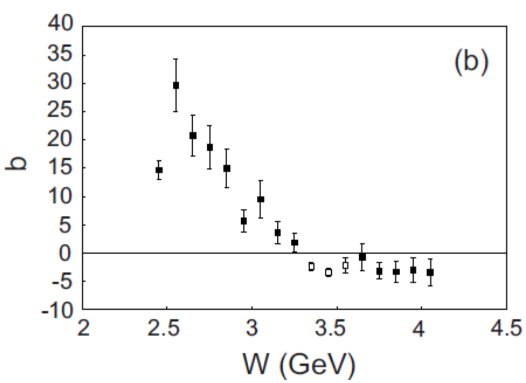
mode	$\omega\phi$	$\phi\phi$	$\omega\omega$
η_c	< 0.49	$7.75 \pm 0.66 \pm 0.62$	$8.67 \pm 2.86 \pm 0.96$
χ_{c0}	< 0.34	$1.72 \pm 0.33 \pm 0.14$	< 3.9
χ_{c2}	< 0.04	$0.62 \pm 0.07 \pm 0.05$	< 0.64

Belle, PRL108,232001(2012)

γγ→PP'

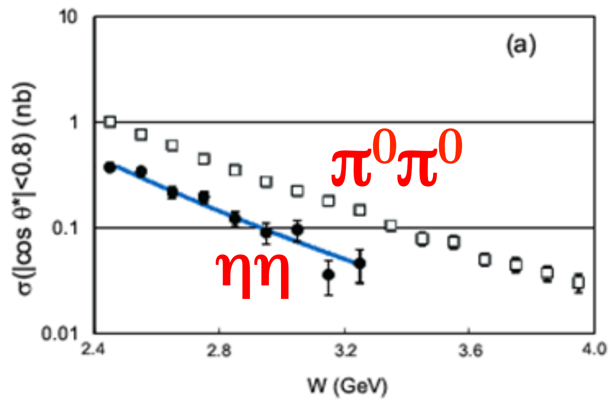
Angular dependence

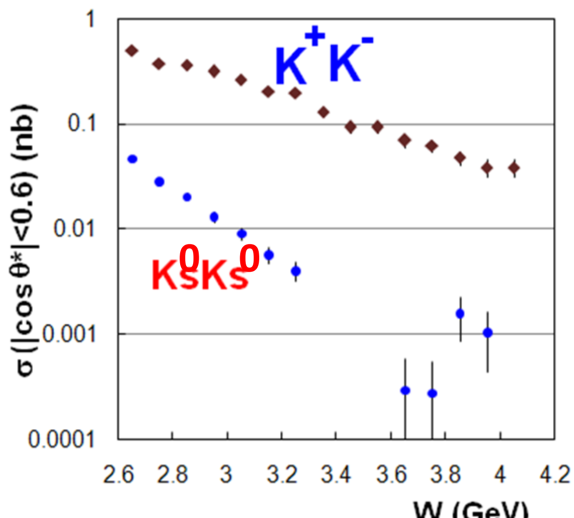




$d\sigma/d|\cos\theta^*| = a(\sin^{-4}\theta^* + b\cos^2\theta^*).$

Energy dependence

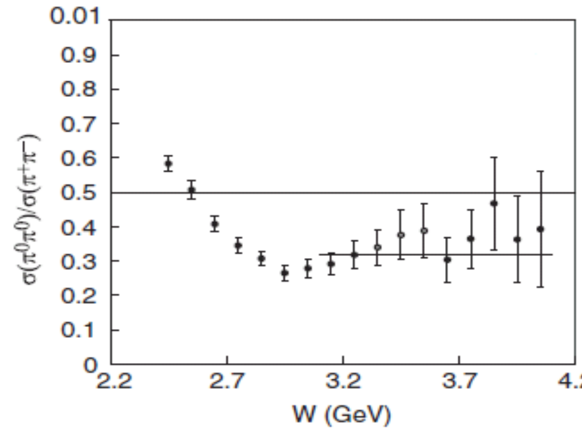




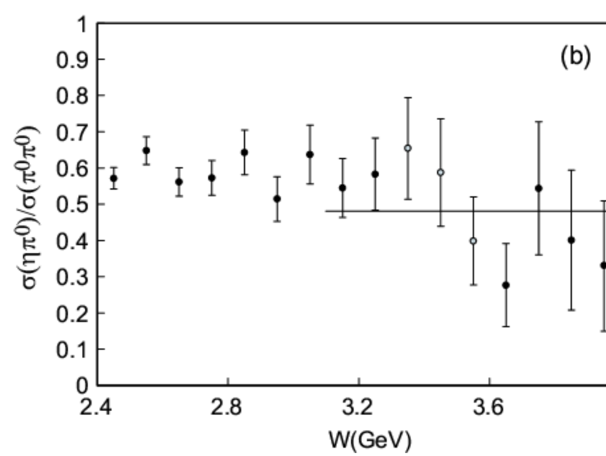
Difference of the slopes
$\sigma \sim W^{-n}$

Cross-section ratio

$\sigma(\pi^0\pi^0)/\sigma(\pi^+\pi^-)$



$\sigma(\eta\pi^0)/\sigma(\pi^0\pi^0)$

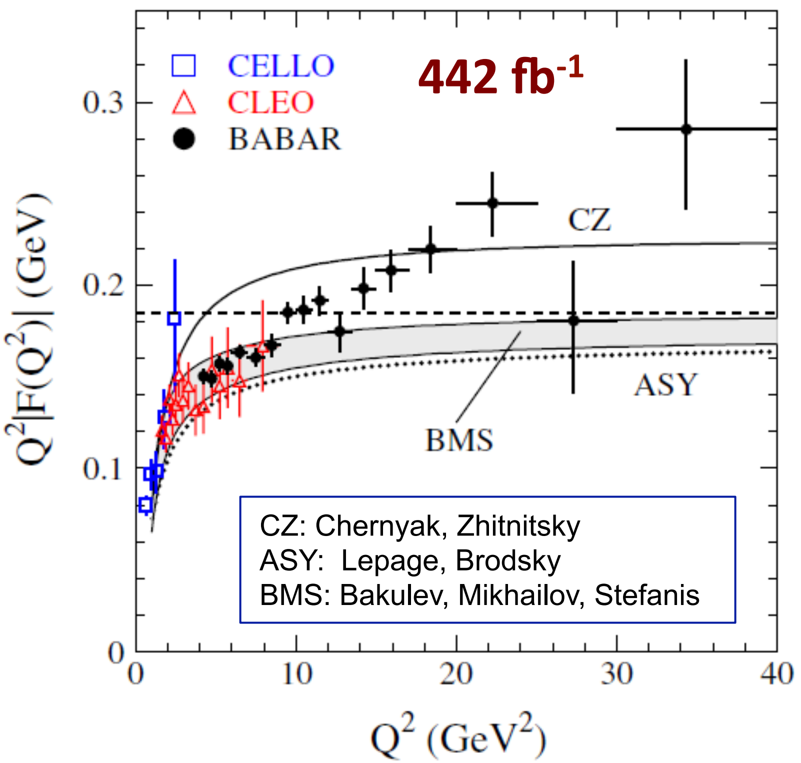


Form factor measurement with single-tag events

π^0 Transition Form Factor (TFF) by BaBar

- Coupling of neutral pion with two photons
- Good test for QCD at high Q^2 ($\rightarrow\infty$): $Q^2 F(Q^2) = \sqrt{2} f_\pi \simeq 0.185$ GeV
- π^0 transition form factor (TFF) measured by BaBar
- Larger than the asymptotic pQCD prediction above Q^2>10GeV^2

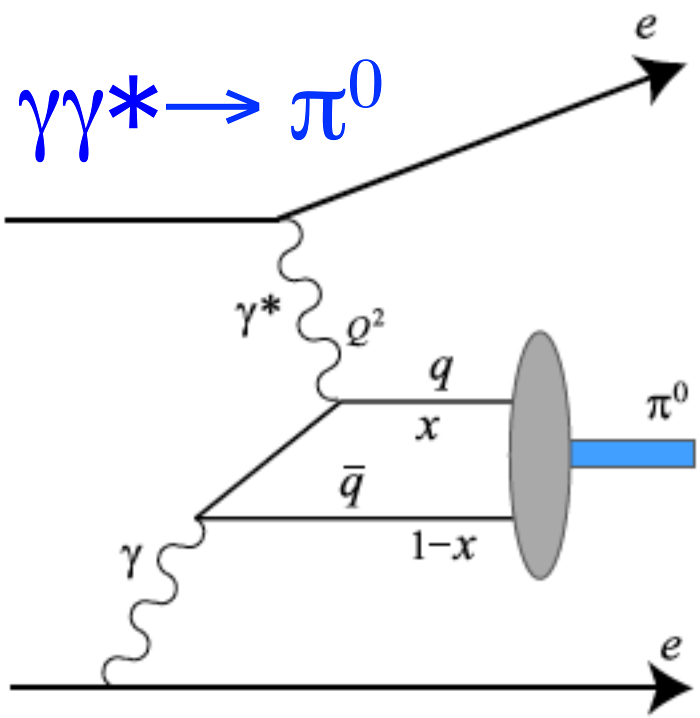
BaBar, PRD 80, 052009 (2009)



- Below Q^2<8GeV^2, the BaBar result supports the CLEO result.
- η and η' TFFs from BaBar [PRD 84, 052001(2011)] are consistent with pQCD predictions.
- Understand this situation for the π^0 TFF's within standard QCD calculations is difficult
- Suggest New Physics beyond standard QCD!

π^0 Transition Form Factor (TFF)

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



- Single-tag π^0 production in two-photon process with a large-Q^2 and a small-Q^2 photon

$$|F(Q^2)|^2 = \lim_{Q_2^2 \to 0} |F(Q^2, Q_2^2)|^2.$$

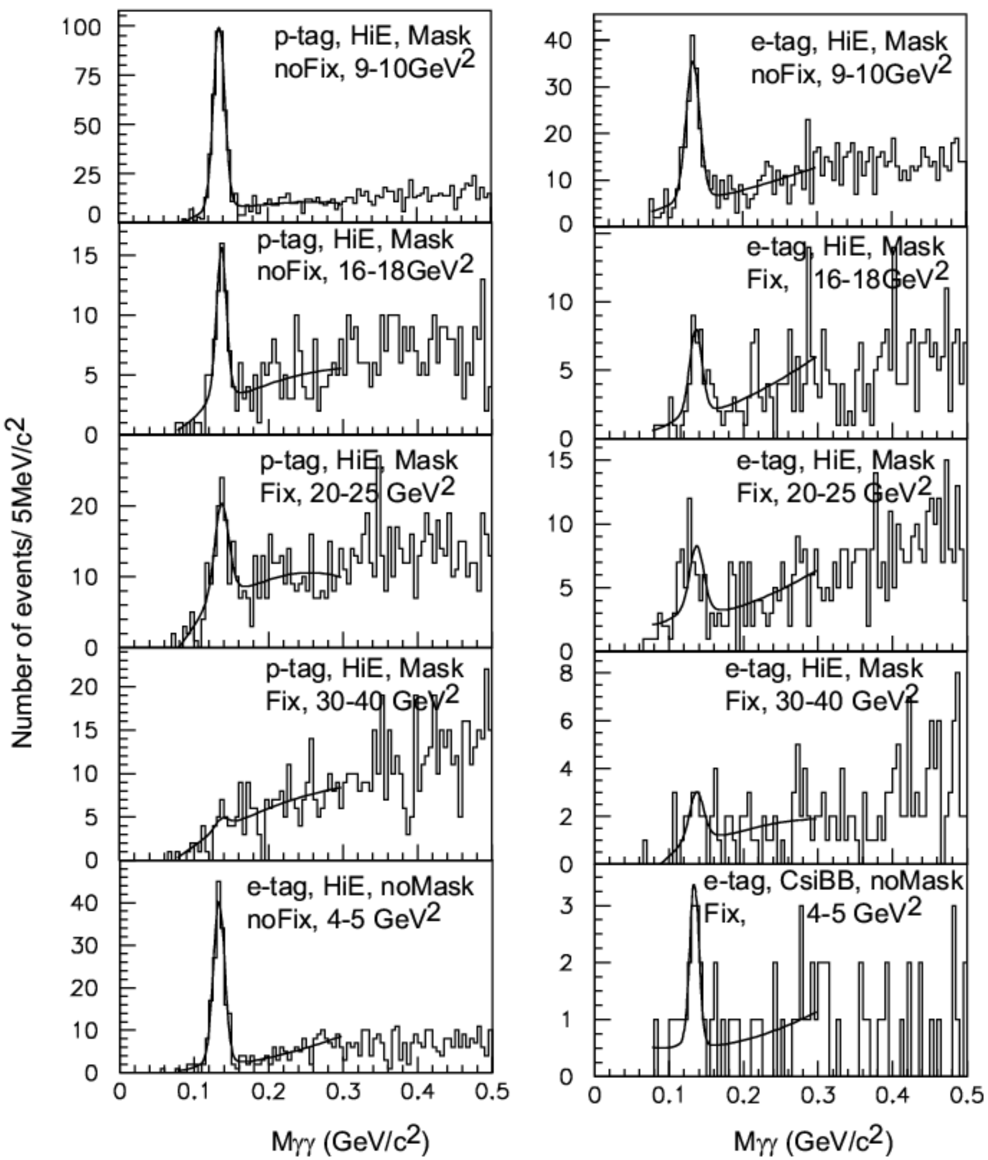
- Detect e+/e- (tag side) and π^0
  $Q^2 = 2EE'(1 - \cos\theta)$ from energy and polar angle of the tagged electron

Event Generator:

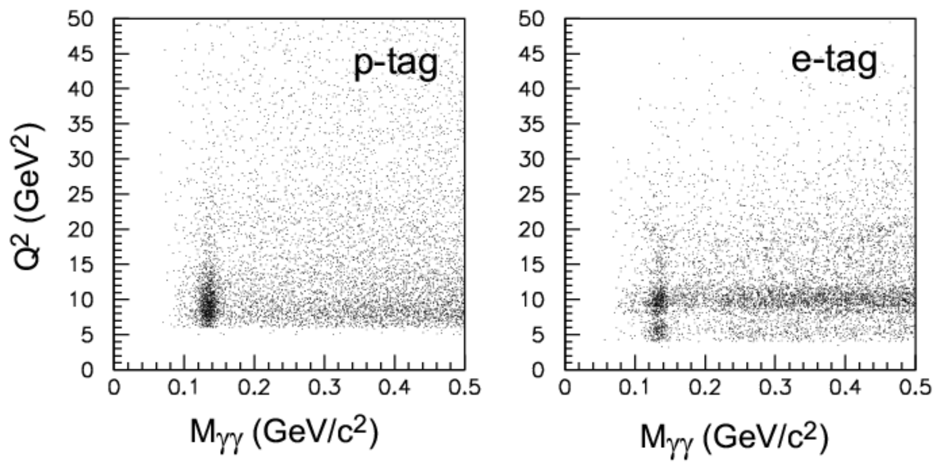
1. TREPS (Two-photonic REsonance Production Simulator) → TREPSBST [http://lss.fnal.gov/archive/other1/kek-report-96-11.pdf]
2. EPA (equivalent photon approximation) →TFF measurement

Extraction of π^0 Yield

Positron-tag **Electron-tag**



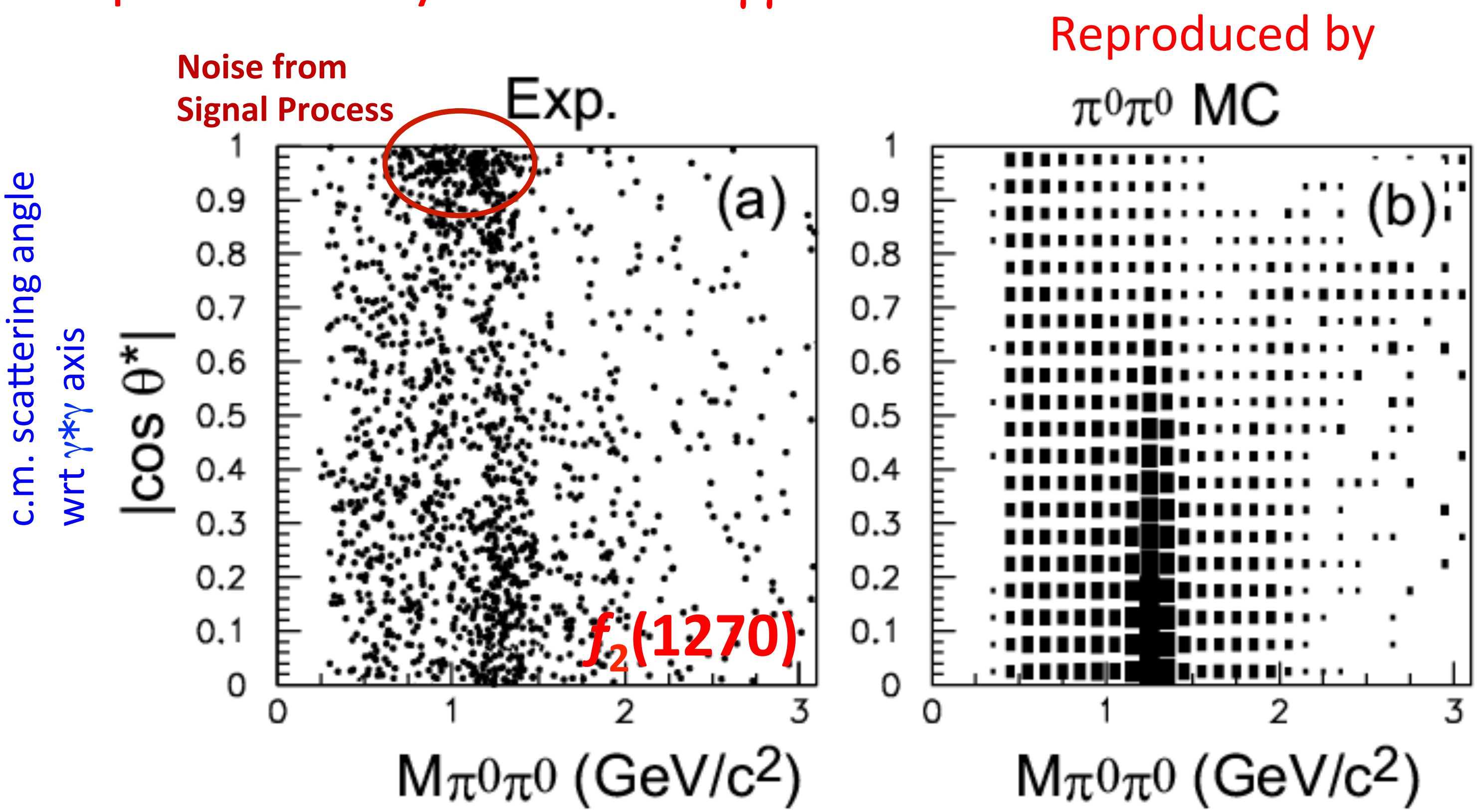
- Int. Luminosity :759 fb^{-1}
- Fit M(γγ) distribution in each Q^2 bin
- Double Gaussian (for signal) +2nd-order Polynomial (for background)



Belle
PRD 86, 092007 (2012)

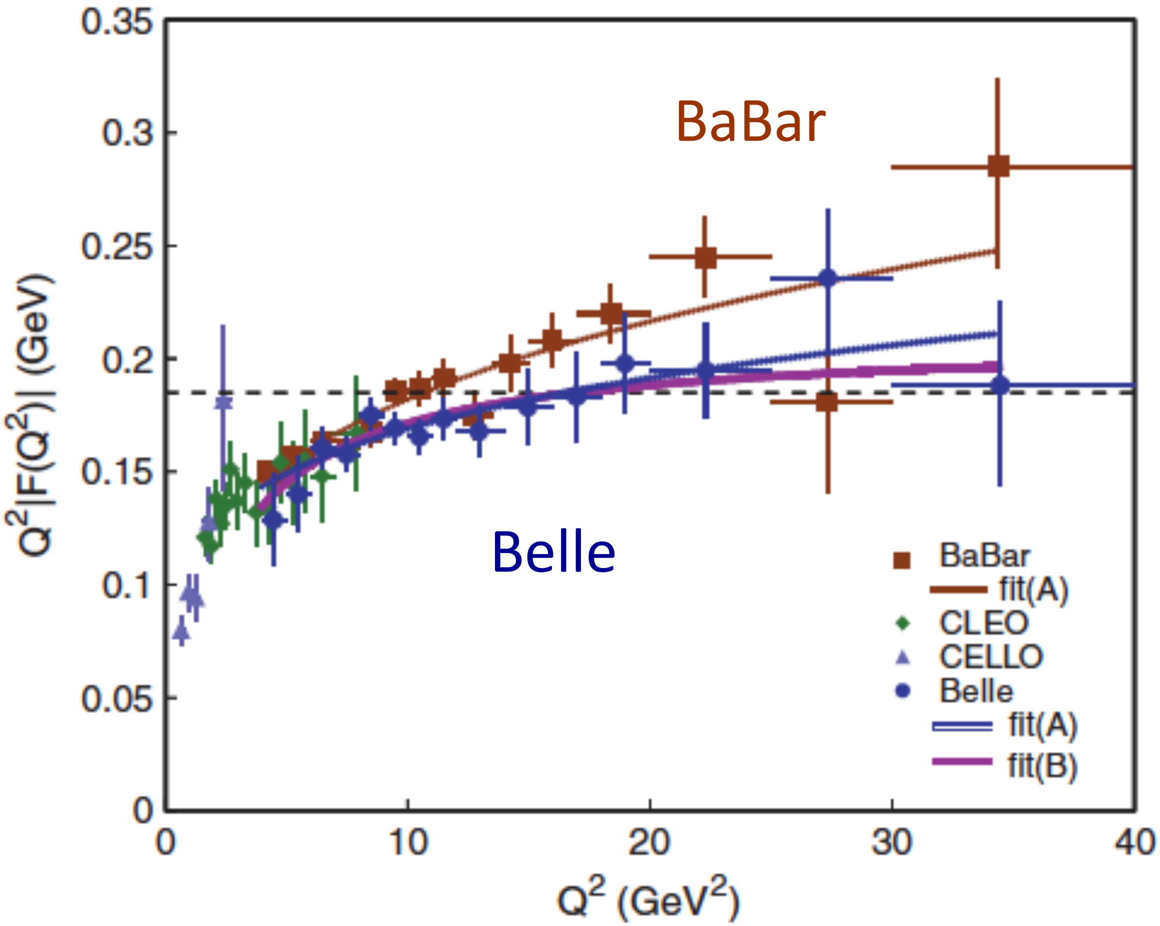
$\pi^0\pi^0$ background MC

Experimentally identified $\gamma\gamma^* \rightarrow \pi^0\pi^0$



Background contamination in signal is estimated by the $\pi^0\pi^0$ **background MC** which is normalized to the observation, **as 2%**

Belle's measurement



Belle
PRD 86, 092007 (2012)

1. Cross sections from p-tag and e-tag are combined

2. No rapid growth above $Q^2 > 9 GeV^2$ (~ 2.3σ difference between Belle and BaBar in 9 – 20 GeV^2)

3. Fit with an asymptotic parameter

$Q^2|F(Q^2)| = BQ^2/(Q^2+C)$

B = 0.209 ± 0.016 GeV

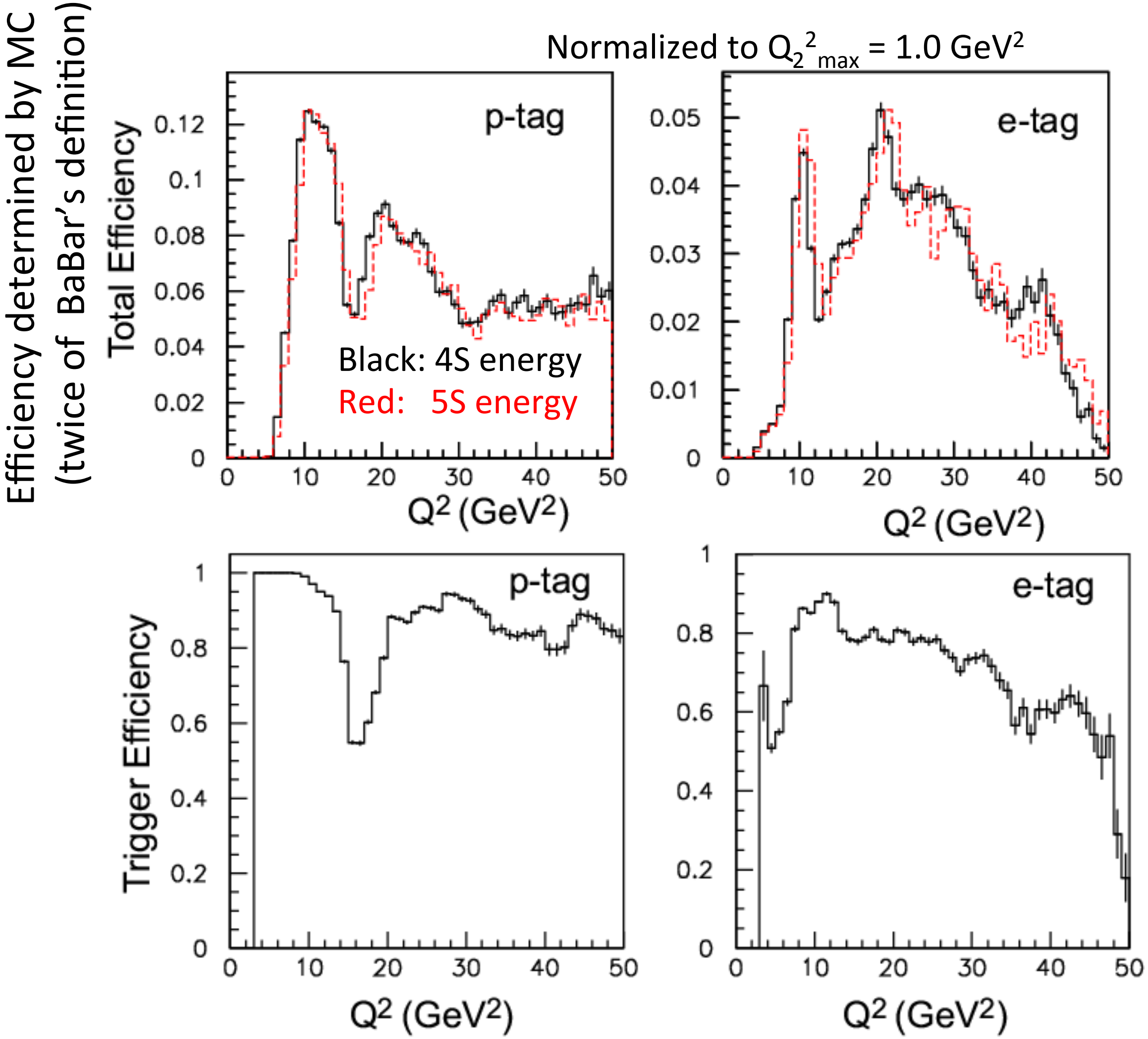
Consistent with QCD prediction (0.185 GeV).

Summary

- Using non-tag two photon events, Belle study hadron spectrum, including charmonium, light hadrons.
- Using single-tag two photon events, Belle has measured the π^0 transition form factor.

Thank you (谢谢)！

Efficiency for the Signal Process at Belle



Up-down structures in the efficiencies are due to complicated Bhabha-veto trigger condition.

The trigger efficiency is defined for the acceptance after the selection