# Exotic hadron search in $\gamma\gamma \rightarrow VV$ process

Z. Q. Liu (劉 智青)

zqliu@ihep.ac.cn

IHEP, Beijing, China

Base on a measurement from Belle Experiment

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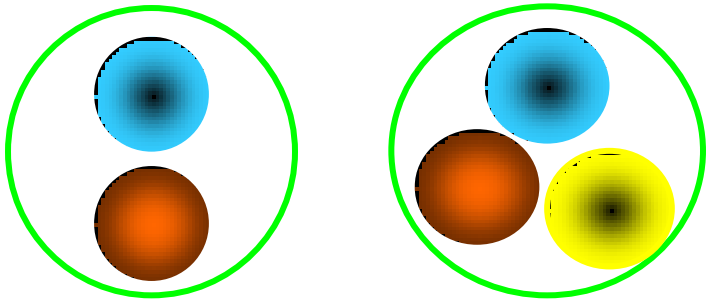
# Outline

- 1. Exotic hadron picture.
- 2. $\gamma\gamma$ reaction in B factory.
- 3. $\gamma\gamma \rightarrow VV$ cross section measurement.
- 4. Summary.

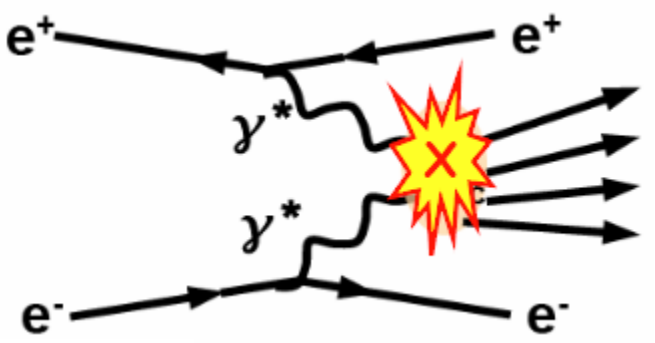
# Hadrons：normal & exotic

- Hadrons are composed from 2 (meson) or 3 (baryon) quarks

Quark model



- QCD allows hadrons with $N_{quarks} \neq 2, 3$
  - glueball : $N_{quarks} = 0$ (gg, ggg, …)
  - hybrid : $N_{quarks} = 2$ + excited gluon
  - Multiquark state : $N_{quarks} > 3$
  - molecule : bound state of more than 2 hadrons




# γ*γ* interaction in an $e^+e^-$ Collider. Hadron production process:

1. High virtuality: large $Q^2$, double tag or single tag method.
2. Quasi-real photons: small $Q^2$, $Q^2 << W^2_{\gamma\gamma}$, $Q^2 << E^2_{QCD}$, non-tag method, characteristic $|\Sigma Pt^*|$ distribution.

Quantum number constraint:

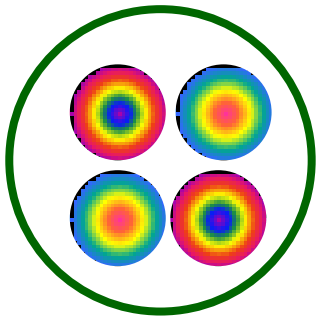
$Q=0$, $C=+$, $J^P=0^+, 0^-, 2^+, 2^-$ …

## Experimental measurements report:

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

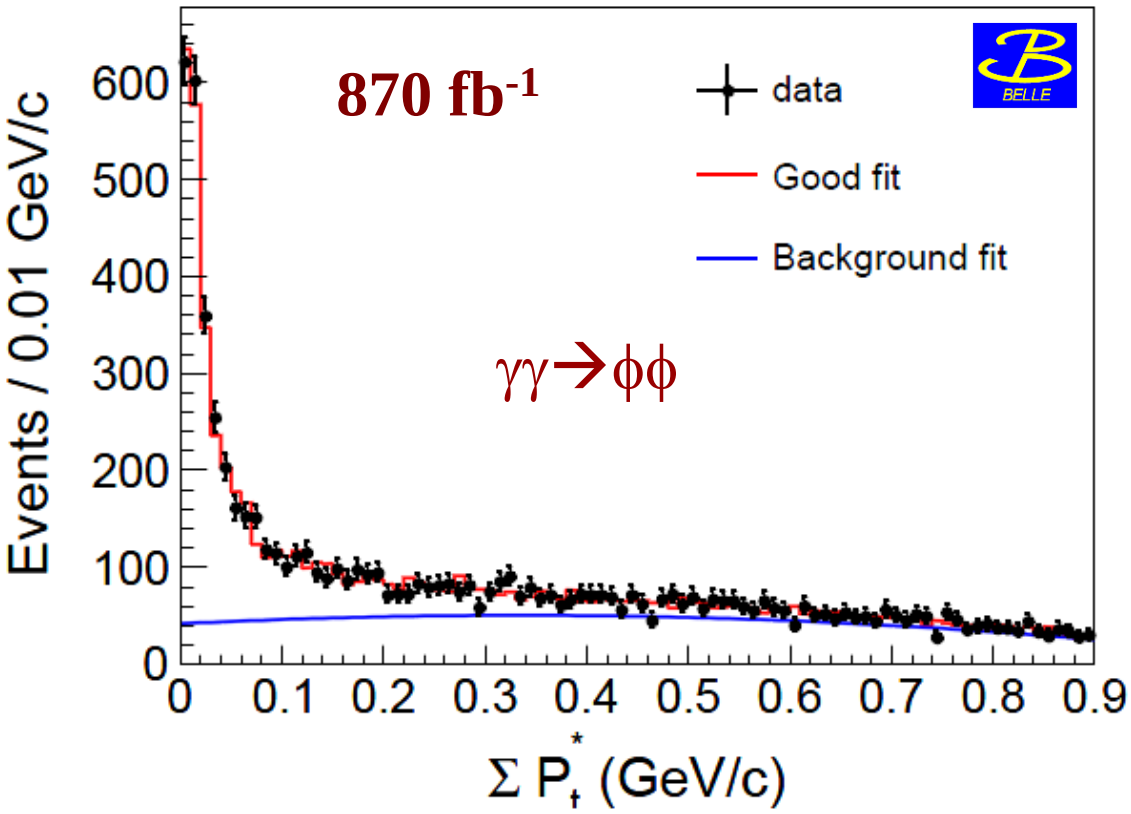
Hunt new hadrons, study hadron structure, test QCD properties and form factors measurement…

- 1. $\gamma\gamma \rightarrow VV$ is good channel for 4-quark state search.
- Consist of VV pair and well "glued" to $\gamma\gamma$ system, lot of models: MIT bag… (Sov. Phys. Usp. 34,1991)
- $\gamma\gamma \rightarrow \rho^+\rho^-, \rho^0\rho^0, K^{*+}K^{*-}$… Measured by L3 and ARGUS.
- Enhancements have been observed above threshold, what's the nature of them?
- 2. We are aiming at $\gamma\gamma \rightarrow \omega\phi, \phi\phi, \omega\omega$.



# $\gamma\gamma \rightarrow VV$ ($\omega\phi$, $\phi\phi$, $\omega\omega$) cross section

# How to extract signal events?




γγ→ωφ, φφ, ωω

φ→K⁺K⁻ ,ω→π⁺π⁻π⁰

L=870fb$^{-1}$ , Y(nS) n=1,…,5

1. Quasi-real photon:

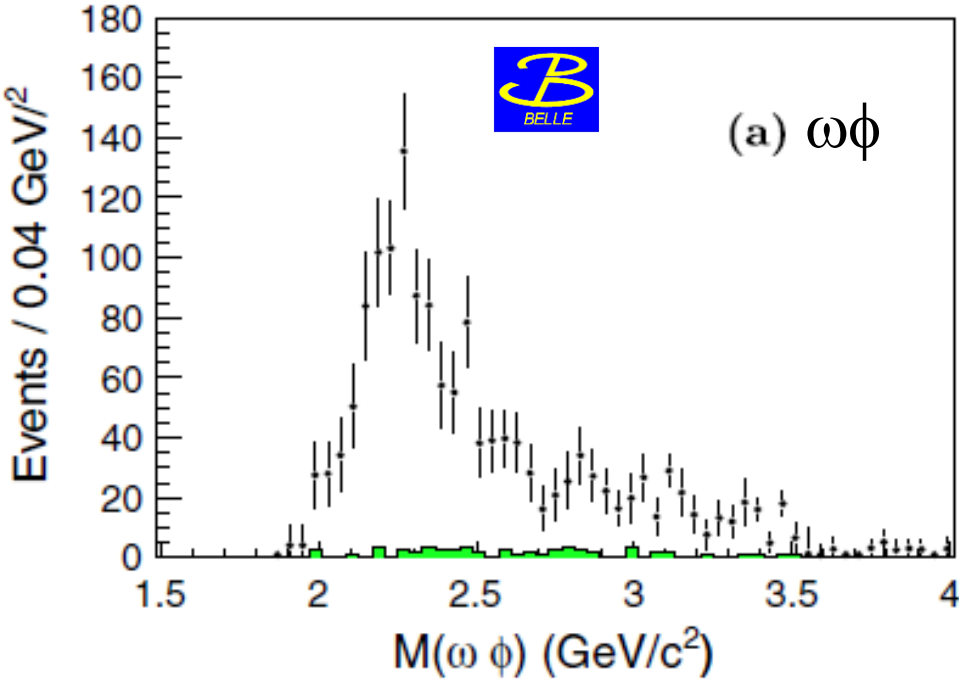
Double un-tag method.

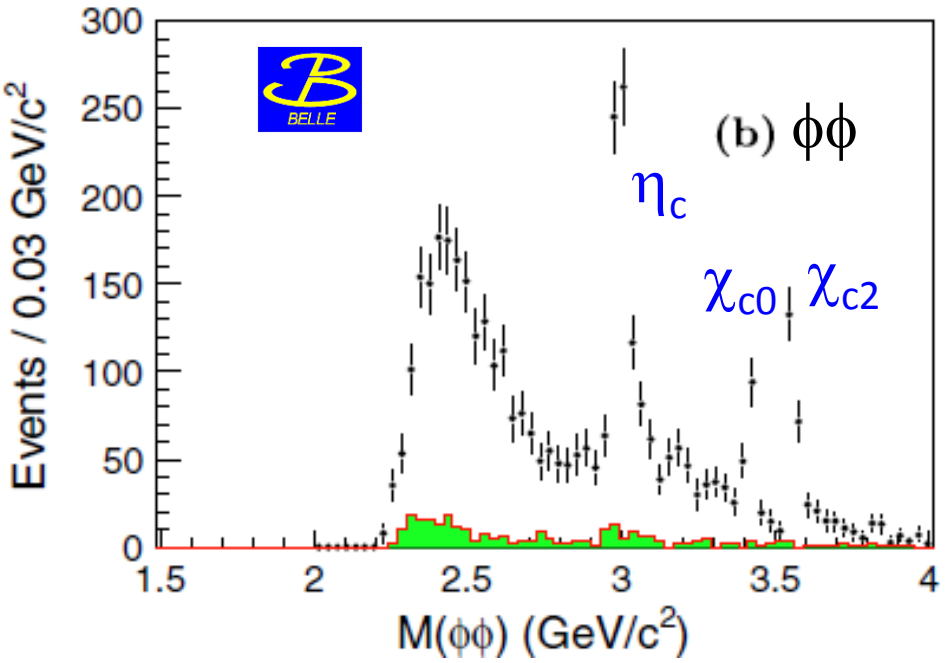
2. Signal events: |ΣPt*| (vector sum) distribution peak at zero.

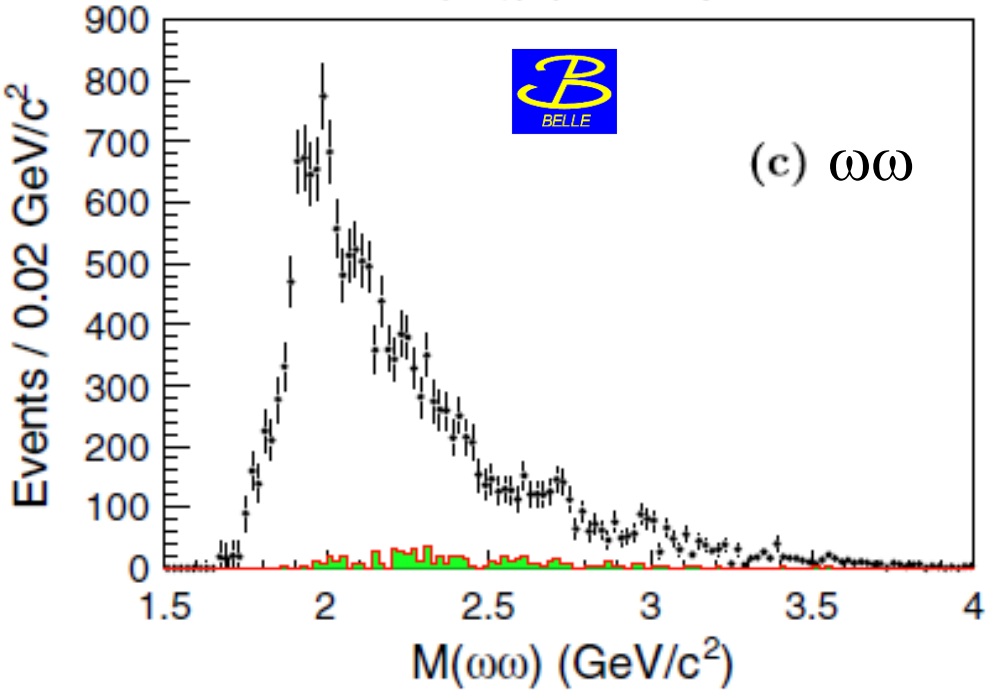
3. Background events: relative large |ΣPt*| value.

4. Pure signal events is extracted through fit |ΣPt*| distribution with smooth background shape in each mass bin.

5. Direct final state background is estimated through ω/φ sideband events.




1. (a) ωφ (b) φφ (c) ωω 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 φφ mode.

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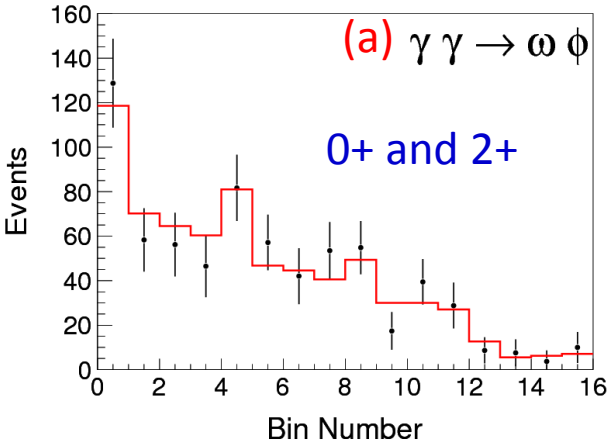
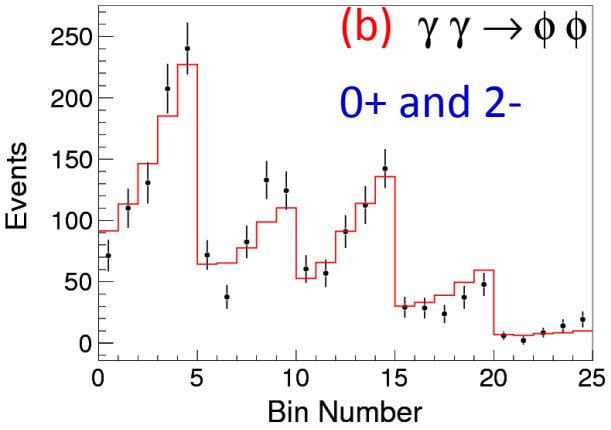
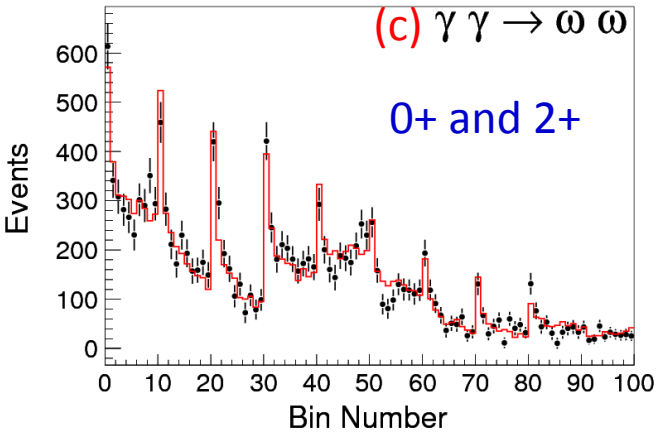
# Spin-Parity results for M(VV)<2.8GeV/$c^2$




Angle definition:

1. Five kinematically independent angles: cosθ, cosθ*,cosθ**,ϕ*,ϕ**

2. Transversity angle: $\phi_T=|\phi^*+\phi^{**}|$;  Polar-angle product: $\Pi_\theta=(\sin\theta^*)^2\times(\sin\theta^{**})^2$

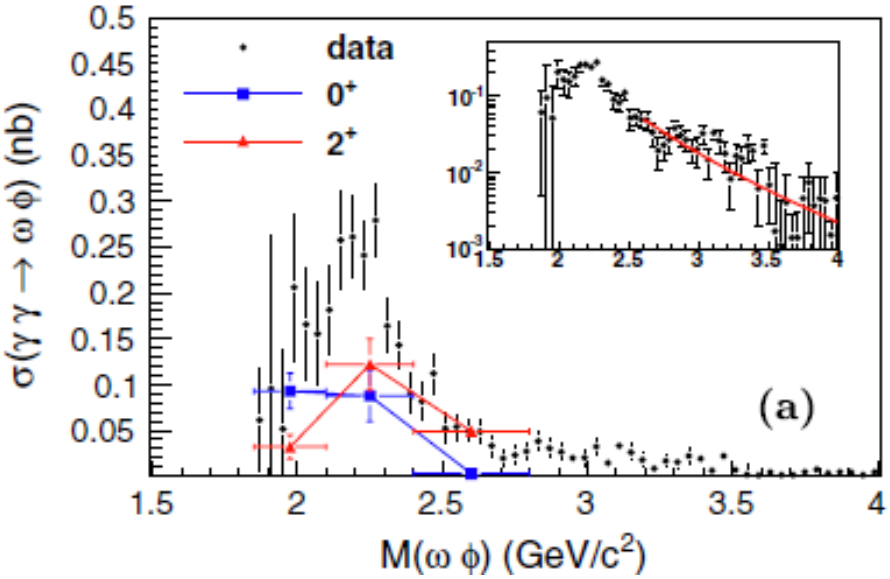
3. (a)4×4 (b)5×5 (c)10×10 bins. Fig (a) shows $\Pi_\theta$ distribution in each $\phi_T$ bin, i.e. $\Pi_\theta$ distribution while $\phi_T\in$ [0.0.25) for first 4 bins and similarity for others.

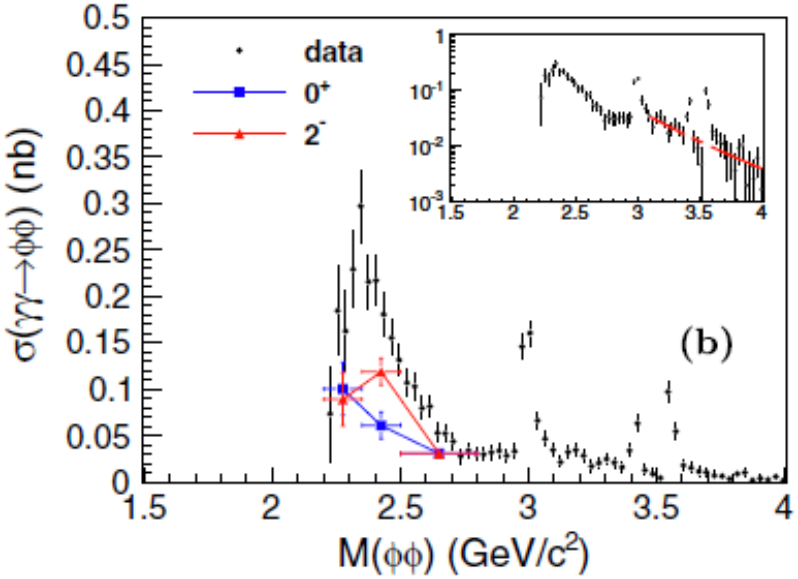
4. Fit 2-D angle distribution $f(\phi_T, \Pi_\theta)$ to extract different $J^P$ components.

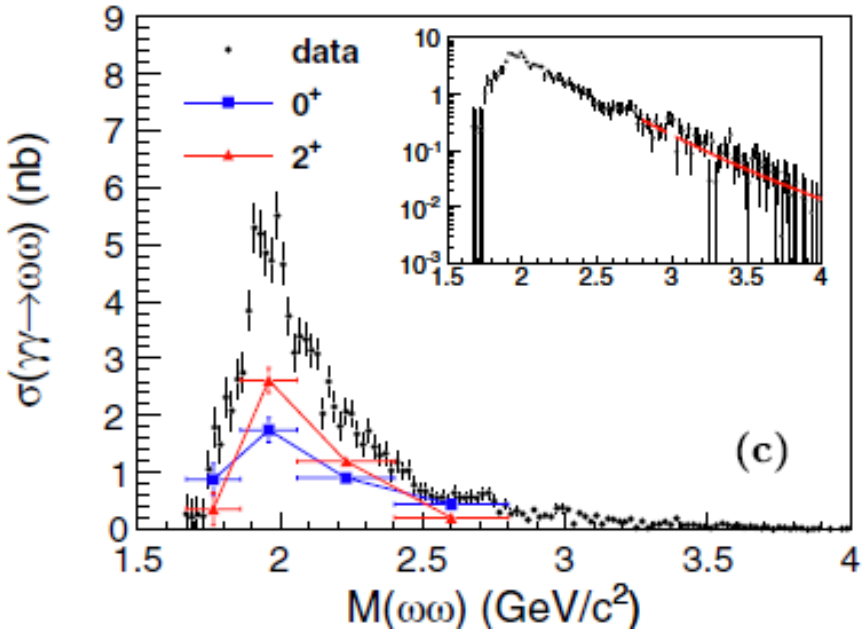
(a). $0^+$ S-Wave or $2^+$ S-Wave

(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. Systematic would be (a)15%, (b)11% and (c)13%.

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

n=(a)7.2±0.6, (b)8.4±1.1, (c)9.1±0.6.

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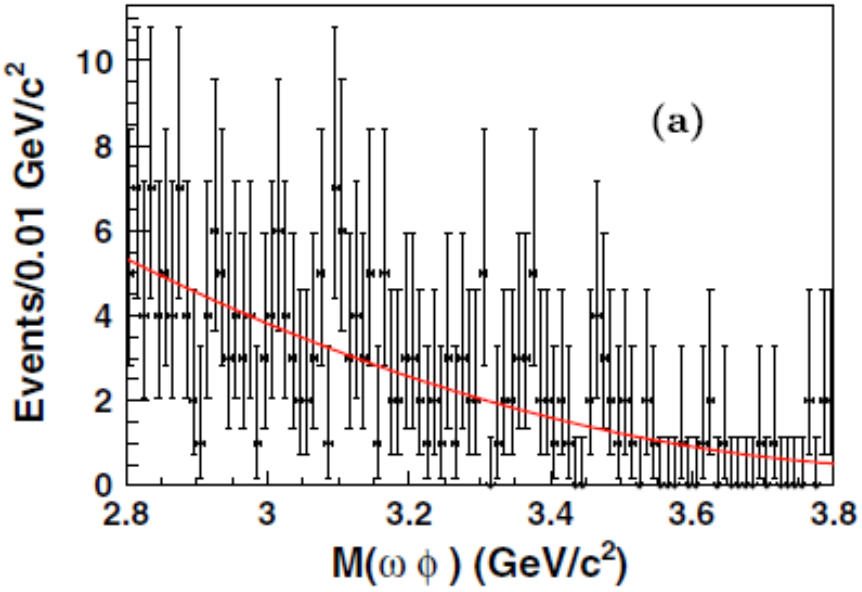
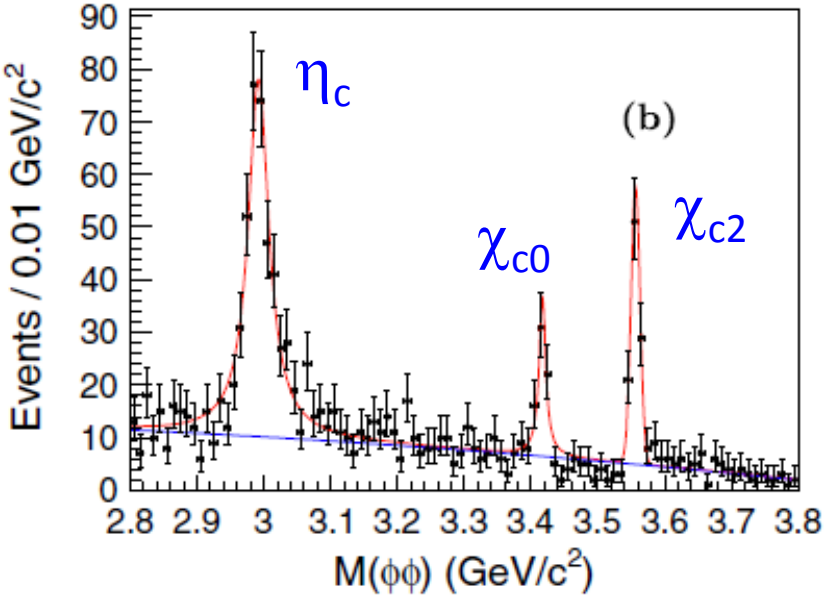
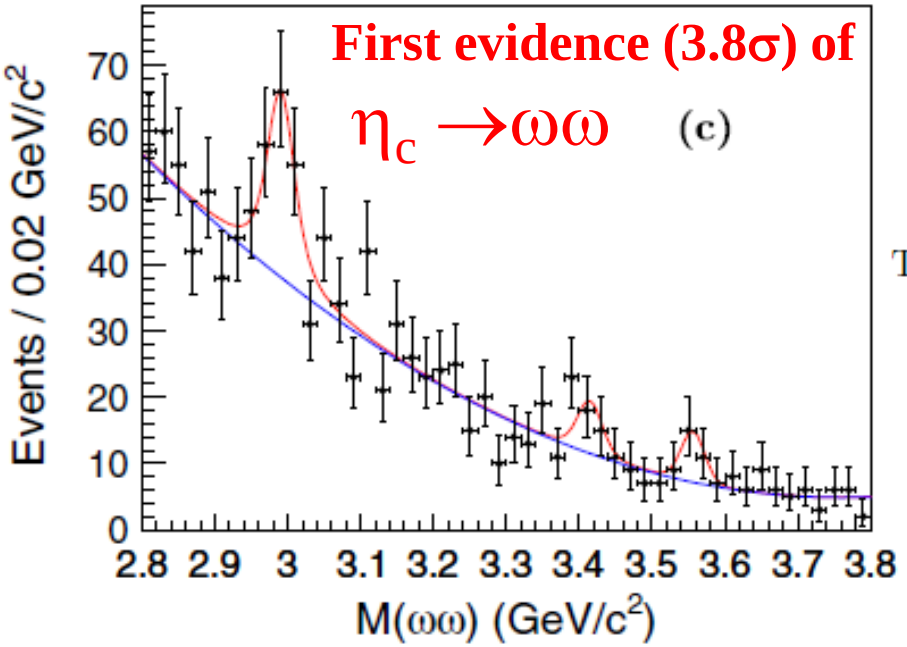
# Charmonium results




1. Clear $\eta_c$, $\chi_{c0}$ and $\chi_{c2}$ 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 $\eta_c$, $\chi_{c0}$ and $\chi_{c2}$.

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

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# Summary

- 1. Cross section of $\gamma\gamma \rightarrow \omega\phi$, $\phi\phi$, $\omega\omega$ process have been measurement up to 4 GeV.
- 2. Structures have been observed near threshold, which might be 4 quark state candidate.
- 3. Agree with perturbative QCD calculation in high energy region.
- 4. Charmonium results are also given.

Thank you!