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

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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 $N_{\text{quarks}} \neq 2, 3$
  - glueball: $N_{\text{quarks}} = 0$ (gg, ggg, ...)
  - hybrid: $N_{\text{quarks}} = 2 + \text{excited gluon}
  - Multiquark state: $N_{\text{quarks}} > 3$
  - molecule: bound state of more than 2 hadrons
\( \gamma \gamma \) 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 \( Q^2 \), \( Q^2 \ll W^2_{\gamma \gamma} \), \( Q^2 \ll E^2_{QCD} \), non-tag method, characteristic \( |\Sigma \text{Pt}^*| \) distribution.

Quantum number constraint:
\( Q=0, \ C=+, \ J^p=0^+, \ 0^-, \ 2^+, \ 2^- \ ...

Experimental measurements report:
\[ \Gamma_{\gamma \gamma} \text{Br}(\gamma \gamma \to f) \text{ or } \gamma \gamma \to f \text{ cross section, } \gamma \gamma \text{ coupling constant, provide info of hadron structure.} \]

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)

• $\gamma\gamma \rightarrow \rho^+\rho^-, \rho^0\rho^0, K^+K^0, K^0K^0$... 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?

2. Signal events: $|\Sigma P_t^*|$ (vector sum) distribution peak at zero.
3. Background events: relative large $|\Sigma P_t^*|$ value.
4. Pure signal events is extracted through fit $|\Sigma P_t^*|$ distribution with smooth background shape in each mass bin.
5. Direct final state background is estimated through $\omega/\phi$ sideband events.

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

$\phi \rightarrow K^+ K^-, \omega \rightarrow \pi^+ \pi^- \pi^0$

$L=870 \text{ fb}^{-1}$, $Y(nS)$ n=1,...,5
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, 6$\pi$...

3. Obvious enhancement below 2.8GeV/c$^2$

4. Charmonia is observed significantly in $\phi \phi$ mode.

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Spin-Parity results for $M(VV)<2.8\,\text{GeV/c}^2$

Angle definition:

1. Five kinematically independent angles: $\cos\theta, \cos\theta^*, \cos\theta^{**}, \phi^*, \phi^{**}$

2. Transversity angle: $\phi_T = |\phi^* + \phi^{**}|$; Polar-angle product: $\Pi_0 = (\sin\theta^*)^2 \times (\sin\theta^{**})^2$

3. (a) $4 \times 4$ (b) $5 \times 5$ (c) $10 \times 10$ bins. Fig (a) shows $\Pi_0$ distribution in each $\phi_T$ bin, i.e. $\Pi_0$ distribution while $\phi_T \in [0.0,0.25)$ for first 4 bins and similarity for others.

4. Fit 2-D angle distribution $f(\phi_T, \Pi_0)$ to extract different $J^P$ components.
   (a). $0^+\text{ S-Wave or } 2^+\text{ S-Wave}$
   (b). $0^+\text{ S-Wave and } 2^-\text{ P-Wave}$
   (c). $0^+\text{ S-Wave and } 2^+\text{ S-Wave}$
1. (a)$\omega\phi$ (b)$\phi\phi$ (c)$\omega\omega$ 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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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 $\Gamma_{\gamma\gamma} \ast Br(VV)$

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**Table II:** Results of $\Gamma_{\gamma\gamma} B(X \rightarrow VV)$ (eV) for $\eta_c$, $\chi_{c0}$ and $\chi_{c2}$.

<table>
<thead>
<tr>
<th>mode</th>
<th>$\omega\phi$</th>
<th>$\phi\phi$</th>
<th>$\omega\omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_c$</td>
<td>$&lt; 0.49$</td>
<td>$7.75 \pm 0.66 \pm 0.62$</td>
<td>$8.67 \pm 2.86 \pm 0.96$</td>
</tr>
<tr>
<td>$\chi_{c0}$</td>
<td>$&lt; 0.34$</td>
<td>$1.72 \pm 0.33 \pm 0.14$</td>
<td>$&lt; 3.9$</td>
</tr>
<tr>
<td>$\chi_{c2}$</td>
<td>$&lt; 0.04$</td>
<td>$0.62 \pm 0.07 \pm 0.05$</td>
<td>$&lt; 0.64$</td>
</tr>
</tbody>
</table>

Belle, PRL108,232001(2012)
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!