Fano-interference picture for *Y*(4008), *Y*(4260) and *Y*(4360)

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QWG2016, 06-10 Jun, 2016 @PNNL

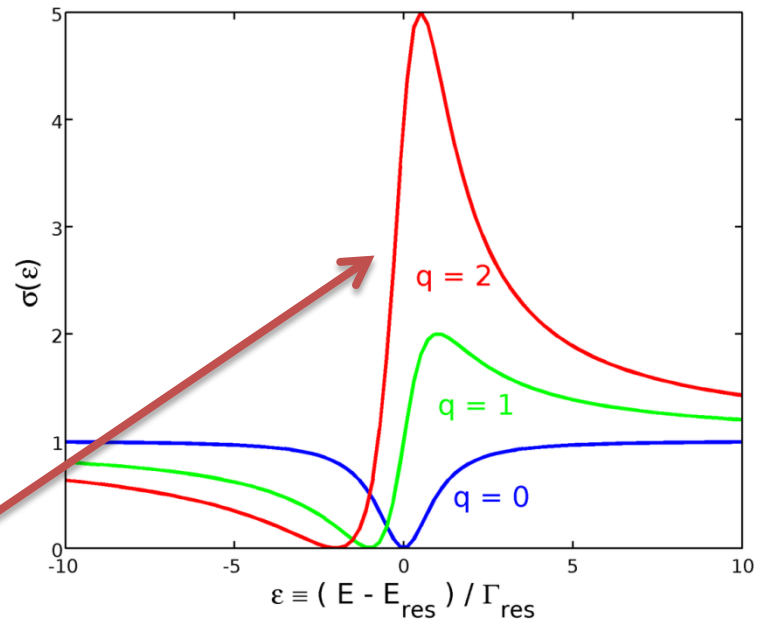
Outline

- Fano Inteference
- $Y(4008)$, $Y(4260)$ and $Y(4360)$
  - Experimental Status & Theoretical Interpretations
- Fano Interference Picture
- Summary

Fano Interference

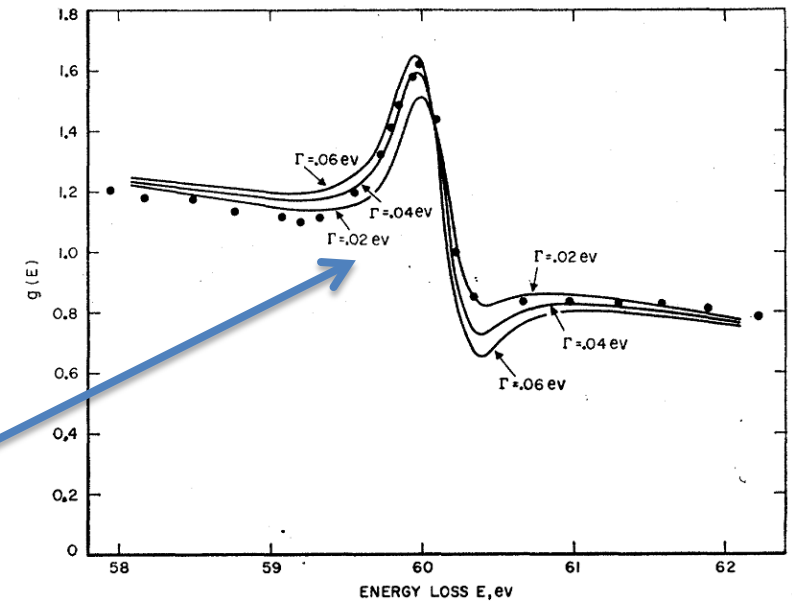
- Fano interference: interference between continuum process (background) and resonant process.

- **Property: change the line shape to asymmetry.**



- **General quantum phenomena**, could be found in atomic physics, nuclear physics, condensed matter physics

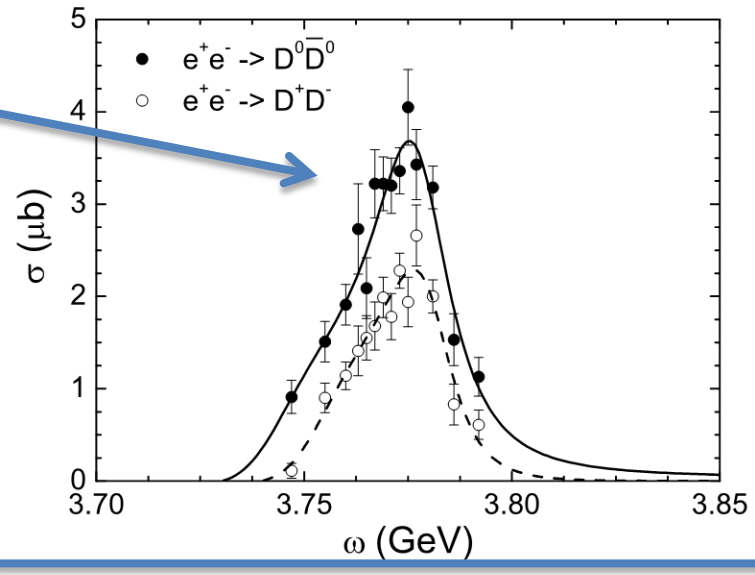
- **Example:** line shape in inelastic electron and Helium



U. Fano, Phys.Rev. 124,1866 (1961).

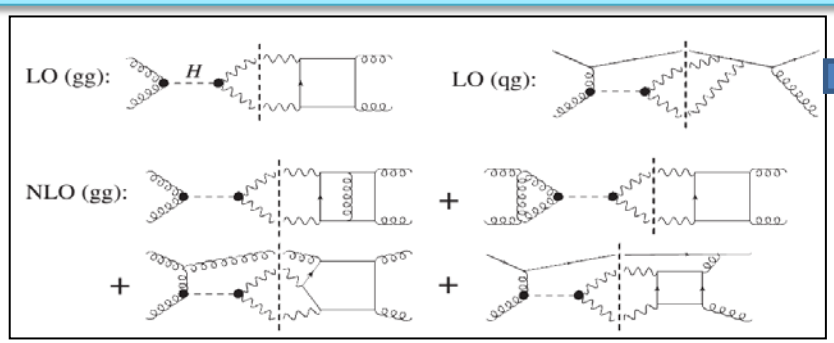
The lineshape of $e^+e^- \to D\bar{D}@\psi(3770)$

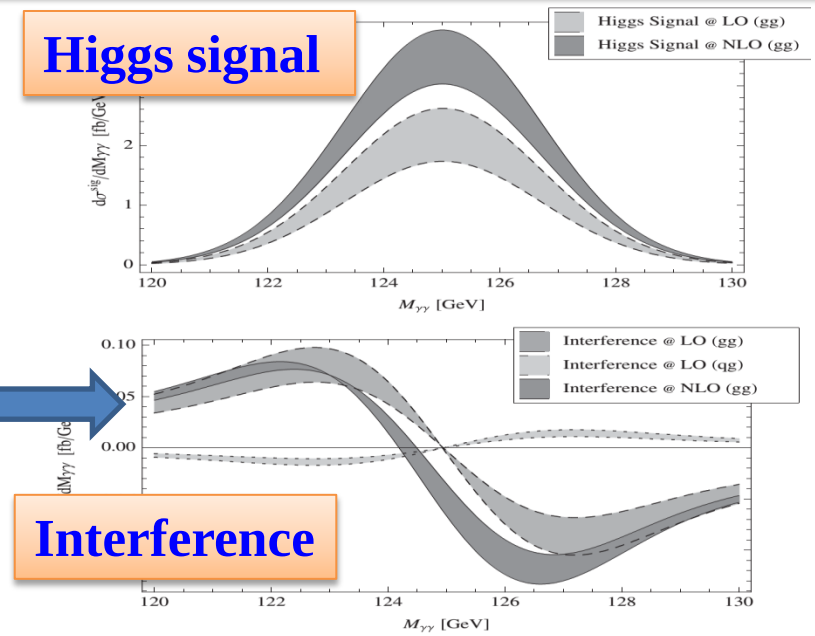
- **The asymmetry lineshape could be explained naturally as a resonance ($\psi(3770)$) in the $D\bar{D}$ continuum.**



Xu Cao and H. Lenske, arXiv:1410.1375

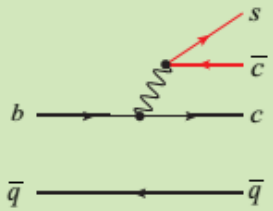
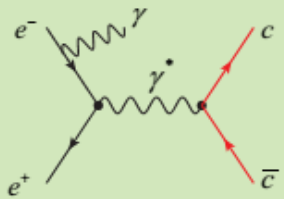
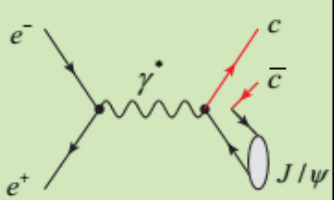
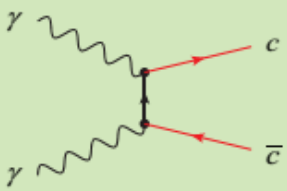
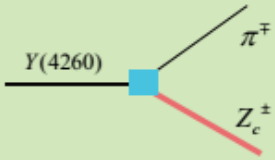
- **The lineshape of the Higgs signals could be asymmetry due to the interference with the continuum contributions**





L. J. Dixon and Ye Li PRL. 111,111802 (2013)

Experimental observation of charmonium-like states

				
$X(3872)$ $Y(3940)$ $Z^+(4430)$ $Z^+(4051)$ $Z^+(4248)$ $Y(4140)$ $Y(4274)$ $Z_c^+(4200)$ $Z^+(4240)$	$Y(4260)$ $Y(4008)$ $Y(4360)$ $Y(4630)$ $Y(4660)$	$X(3940)$ $X(4160)$	$X(3915)$ $X(4350)$ $Z(3930)$	$Z_c(3900)$ $Z_c(4025)$ $Z_c(4020)$ $Z_c(3885)$

- **$Y(4008)$, $Y(4260)$ and $Y(4360)$ are all observed in the e^+e^- annihilation processes, thus J^{PC} quantum numbers of these states are 1^{--} .**

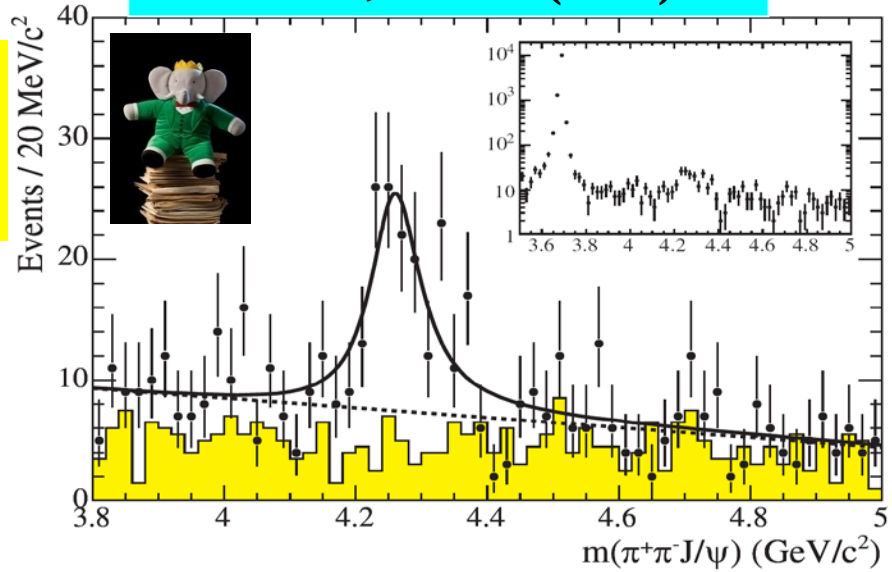
Experimental status of $Y(4008)$, $Y(4260)$ and $Y(4360)$

$$e^+e^- \to \gamma_{\rm ISR}\,\pi^+\pi^- J/\psi$$

$Y(4260)$
$Y(4008)$

Experiment	Mass (MeV)	Width (MeV)
BaBar [1]	$4259 \pm 8^{+2}_{-6}$	$88 \pm 23^{+6}_{-4}$
CLEO [3]	$4284^{+17}_{-16} \pm 4$	$73^{+39}_{-25} \pm 5$
Belle [4]	$4247 \pm 12^{+17}_{-32}$	$108 \pm 19 \pm 10$
PDG2016	**4251 ± 9**	**120 ± 12**

PRL95, 142001 (2005)



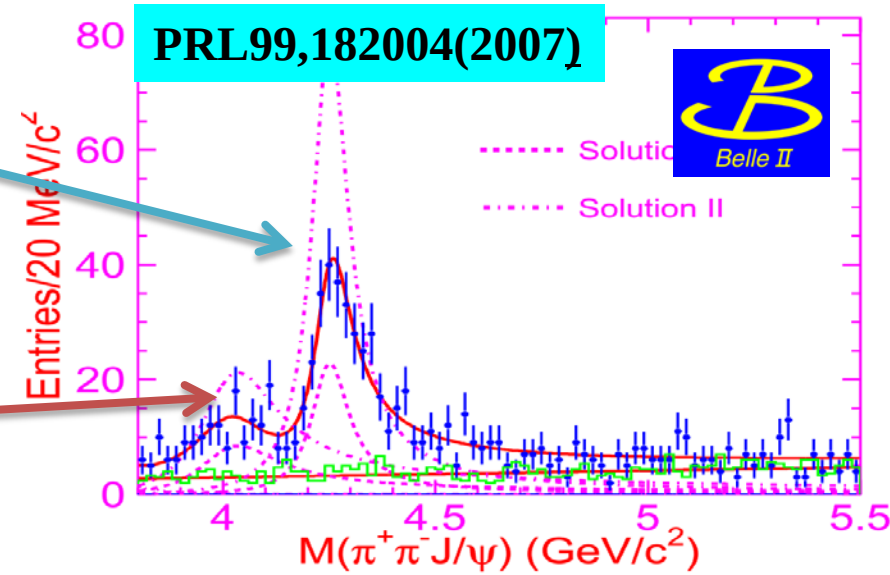
- **The Belle Collaboration confirmed Y(4260)**

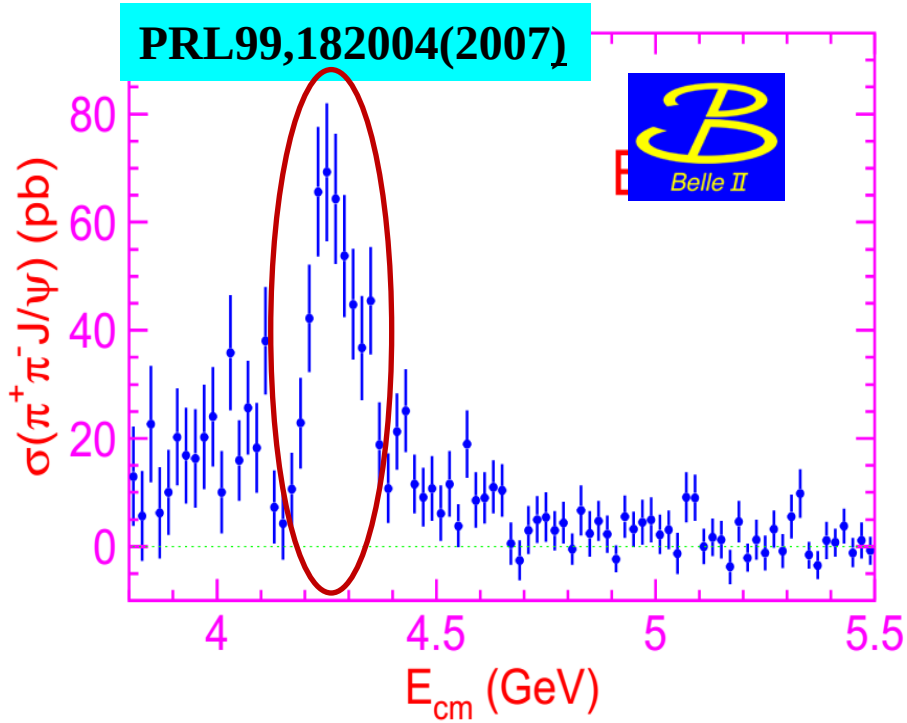
- **New broader structure: Y(4008)**

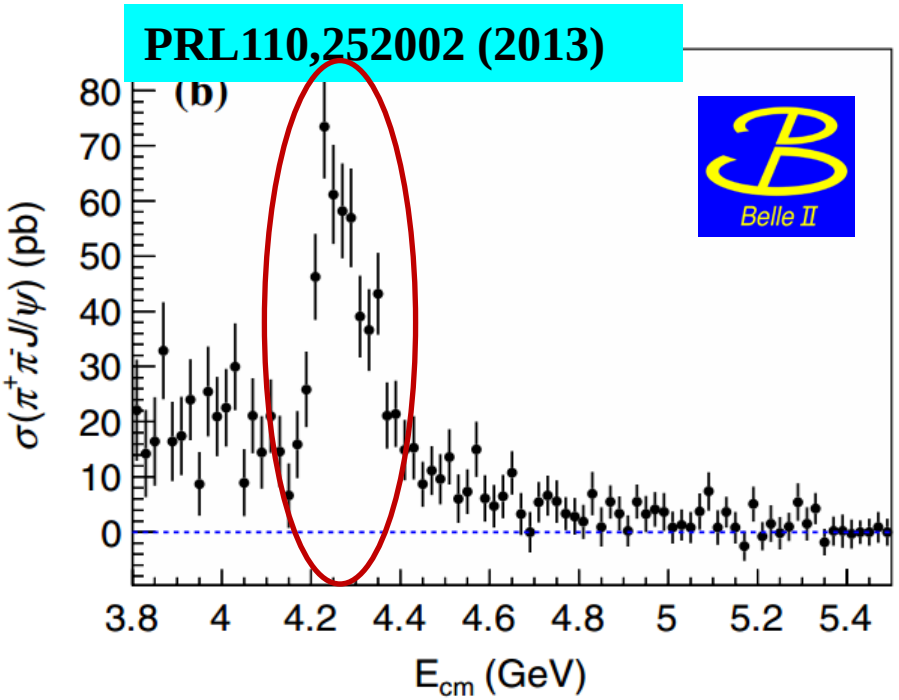
$$m_{Y(4008)} = 4008 \pm 40^{+114}_{-28}\ \text{MeV}$$

$$\Gamma_{Y(4008)} = 226 \pm 44 \pm 87\ \text{MeV}$$

PRL99,182004(2007)





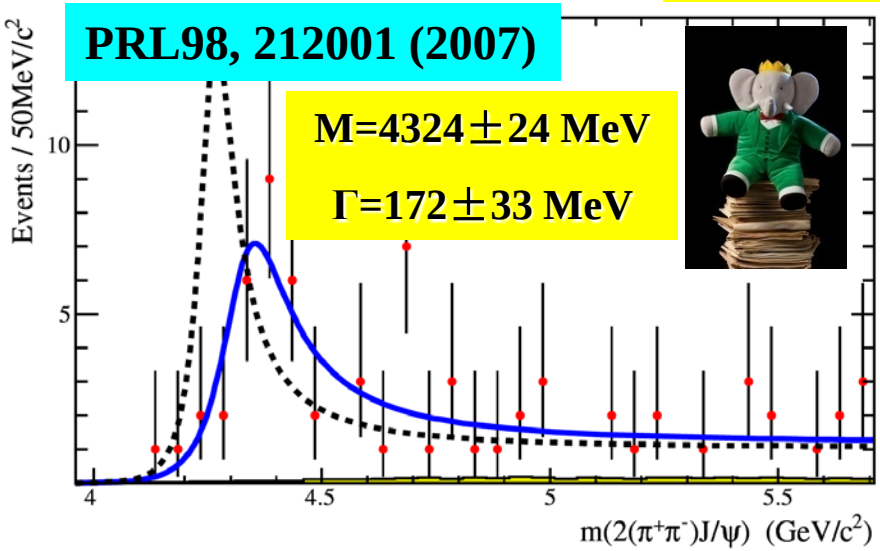


- **Belle Collaboration present the data of the cross sections;**
- $\sigma \simeq 80$ **pb @4.260 GeV;**
- **The lineshape of the cross sections in the vicinity of Y(4260) is asymmetry.**

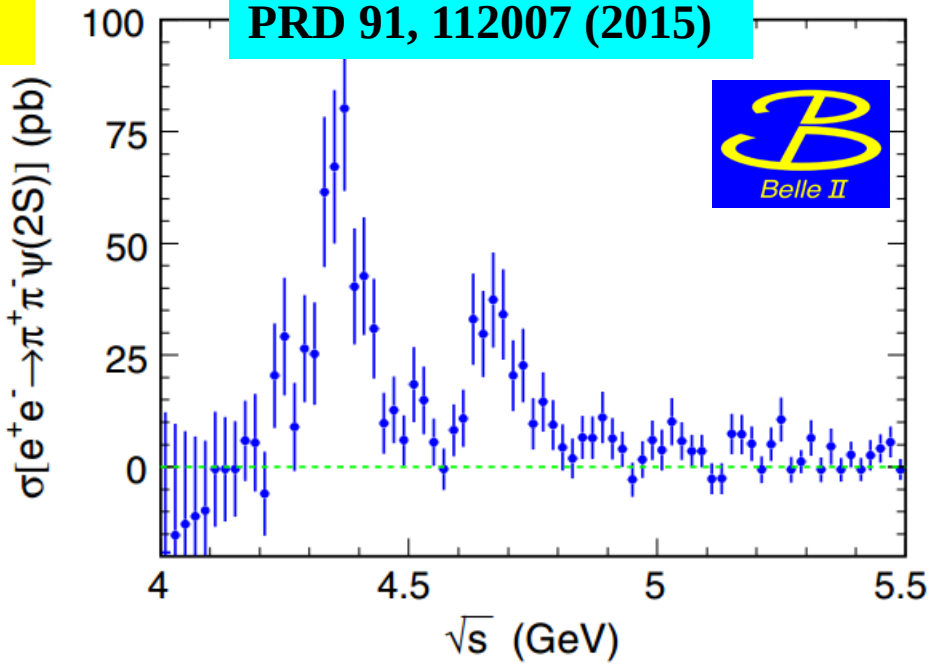
$$e^+e^- \to \gamma_{ISR}\psi(2S)\pi^+\pi^-$$

Y(4360)

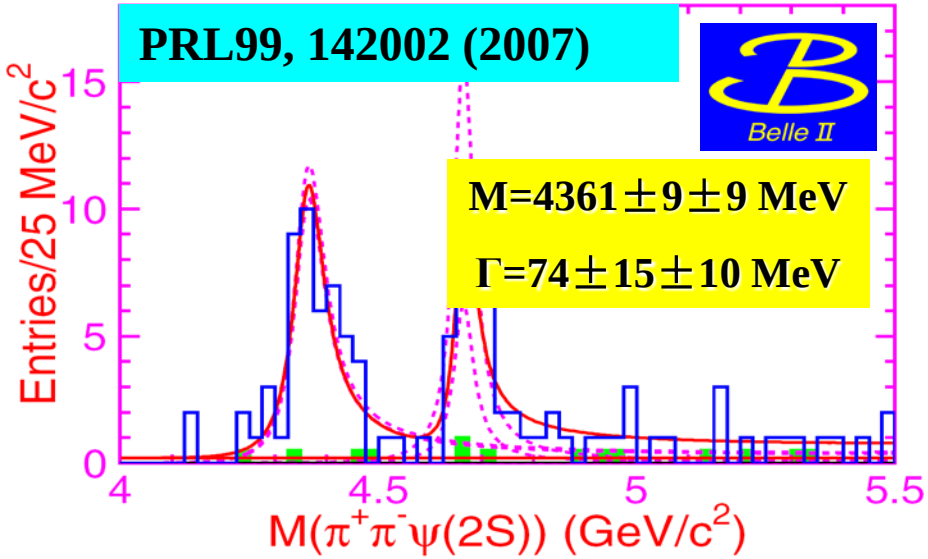
PRL98, 212001 (2007)



PRD 91, 112007 (2015)



PRL99, 142002 (2007)

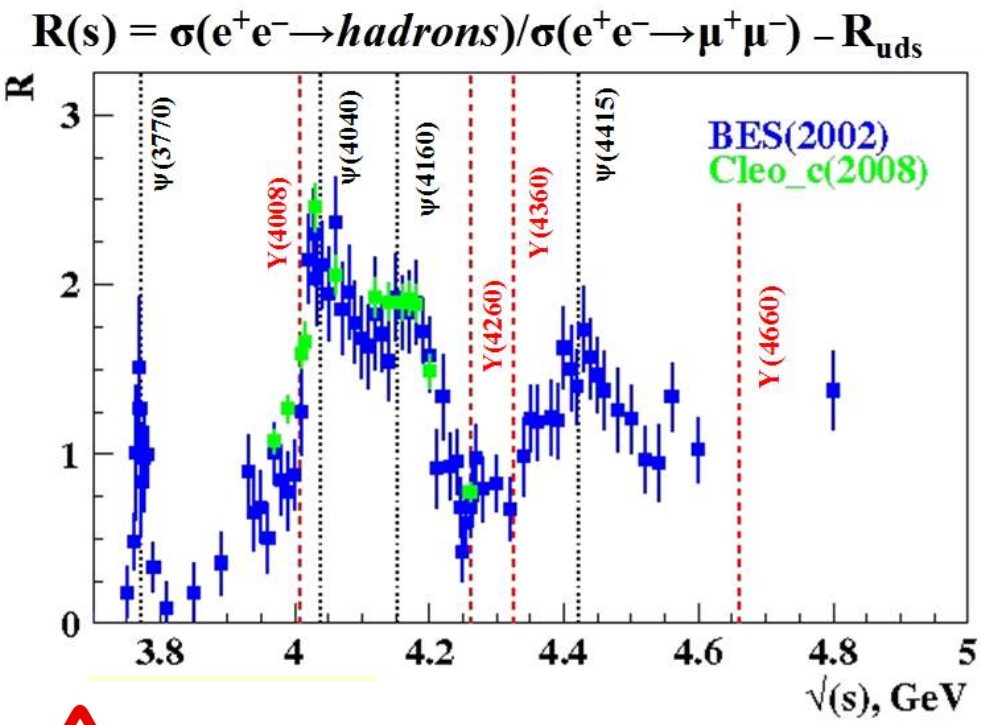


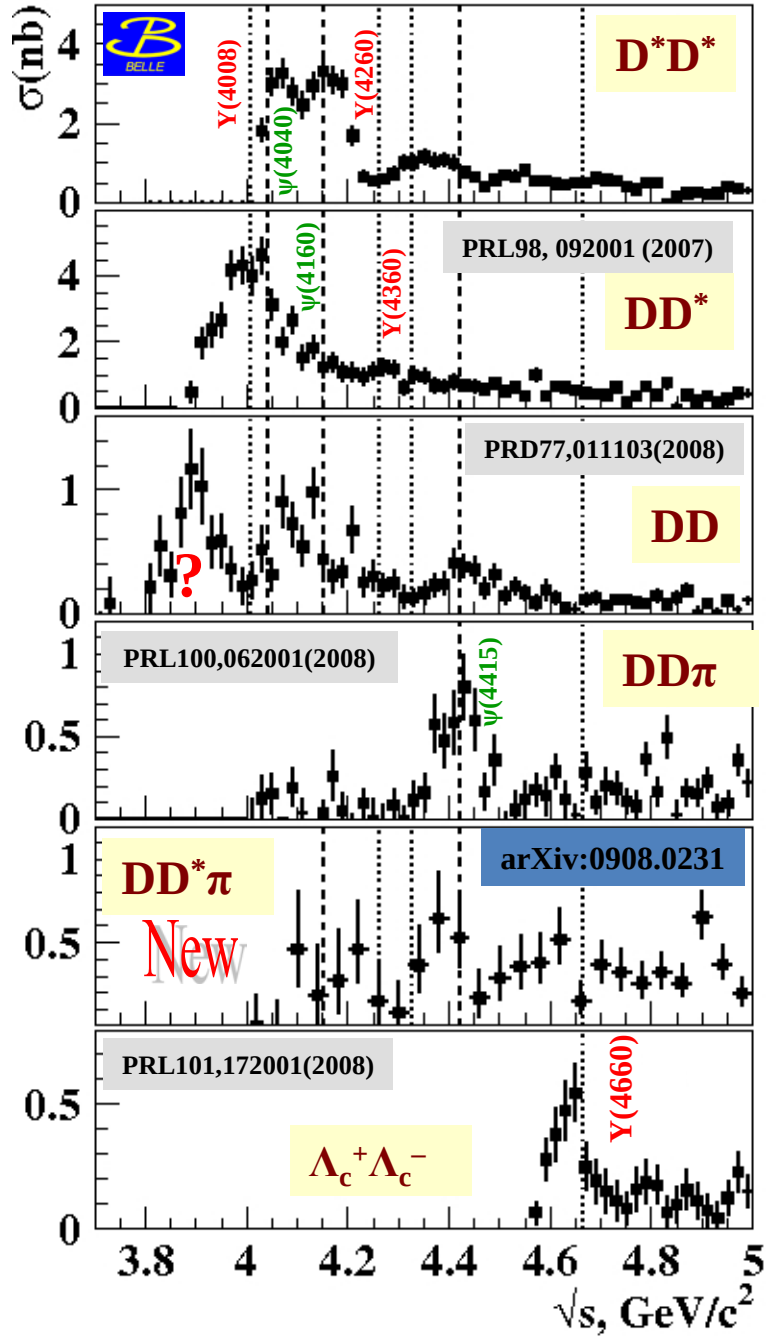
Experiment	Mass(MeV)	Width(MeV)
BaBar(07)	4324±24	172±33
Belle(07)	4361±9±9	74±15±10
BaBar(12)	4340±16±9	94±32±13
Belle(14)	4347±6±3	103±9±5
PDG2016	4353±10	78±16

Theoretical explanation

- Support
- Against
- No definite conclusion

	Exotic state	VS	Conventional $c\bar{c}$
Y(4008)	• $D^*\overline{D^*}$ molecule state PRD80,034005, EPJC54,471, …. • $[cq][\bar{c}\bar{q}]$ tetraquark state CPL. 32,101201, …		• $3S$ charmonium EPJC54,471, EPJC74,3031, ….
Y(4260)	• Charmonium hybrid PLB625,212, PLB631,164, PLB628,215, … • Diquark-antidiquark $[cs][\bar{c}\bar{s}]$ PRD72,031502, EPJC75,550, EPJC58,399, … • Molecular state $D_1\bar{D}$, $D_0\bar{D}^*$, $\chi_{c0}V$ PRD72,054023, PLB634,399, PRD79, 014001, PLB639,263, PRD80,094012, …		• $4S$, 3D, 2^3D_1 charmonium PRD72,031503, PRD79,094004, PRD32,189, …
Y(4360)	• Molecular state PRD92,036006 (ρDD), PRL104,132005($\Lambda_c\overline{\Lambda_c}$), NPA815,53($D_{s0}D_s^*$), PRD81,074033, PRL102,242003 ($D_1\overline{D^*}$(2S)), … • Tetraquark state EPJC74,2874, …		• $3D$ charmonium PRD79,094004, PRD77, 014033, … • $4S$ charmonium PRD78,114033, …



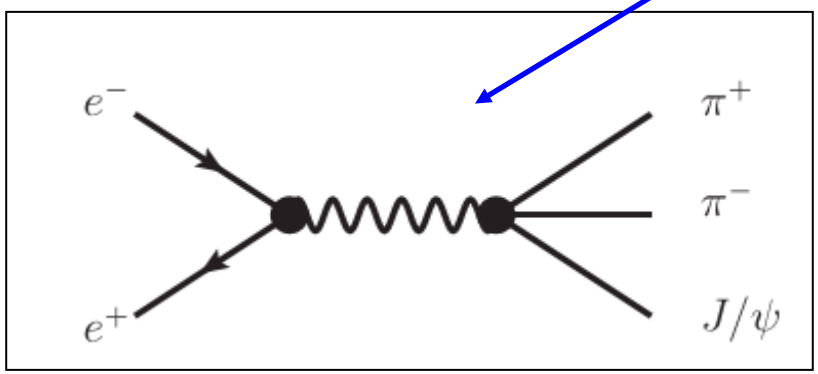


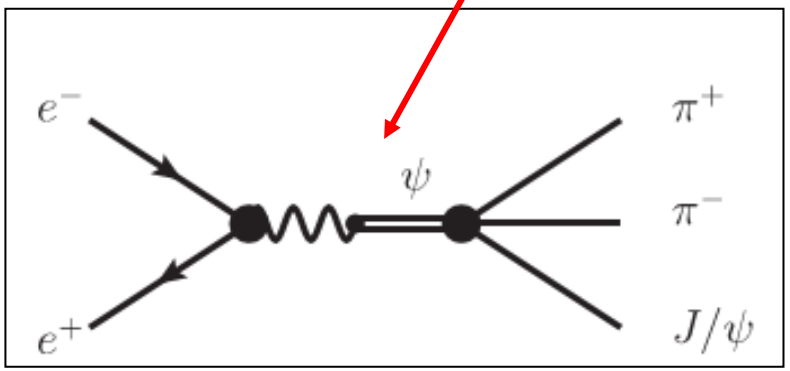
Great challenge:

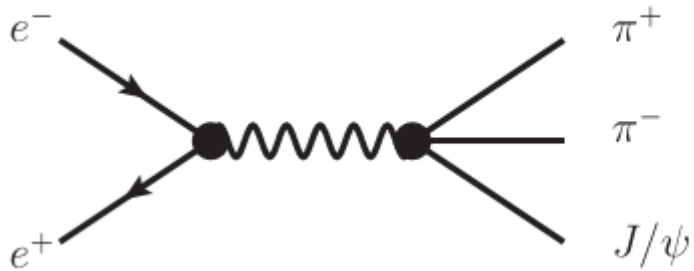
No evidence of *Y*(4008), *Y*(4260) and *Y*(4360) in the obtained open-charm process and *R*-value scan

Fano-interference explanation for $Y(4260)$ and $Y(4360)$

The interference between **Continuum** and **Resonance**

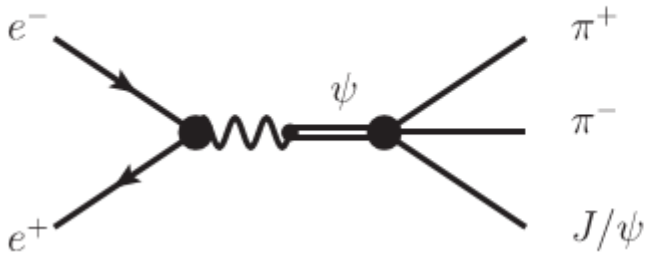






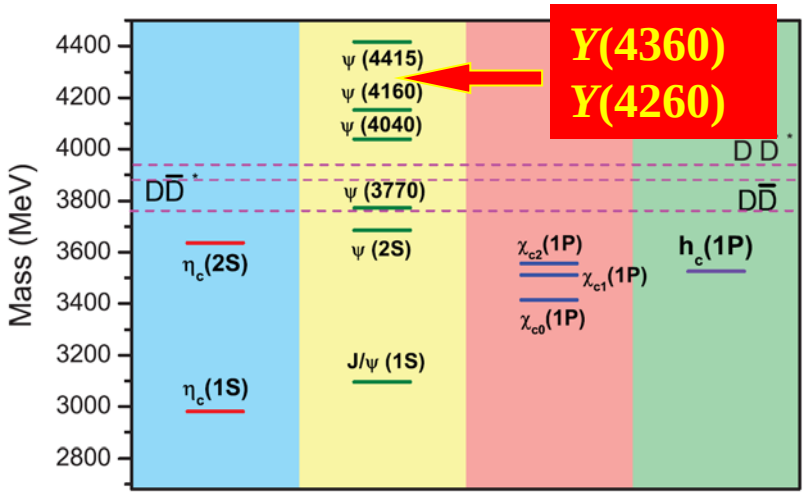
$$\widehat{=} g\, u^2 e^{-a u^2}$$

$$u = \sqrt{s} - \sum_f m_f$$



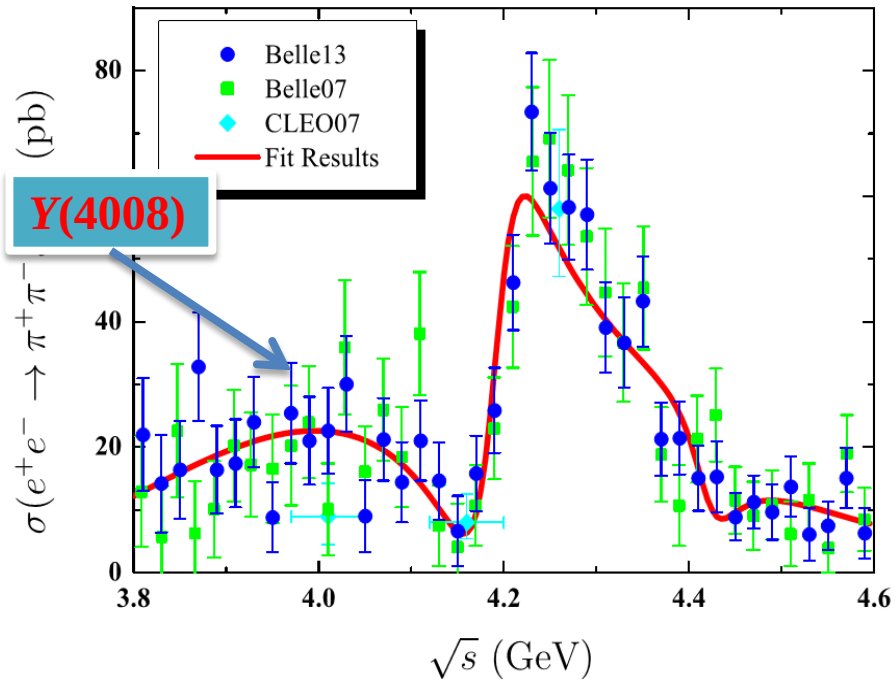
$$\widehat{=} \frac{\sqrt{12\pi\Gamma_\psi^{e^+e^-} \times \mathcal{B}(\psi \to \pi^+\pi^- J/\psi)\Gamma_\psi}}{s - m_\psi^2 + i m_\psi \Gamma_\psi} \sqrt{\frac{\Phi_{2\to3}(s)}{\Phi_{2\to3}(m_\psi^2)}}$$

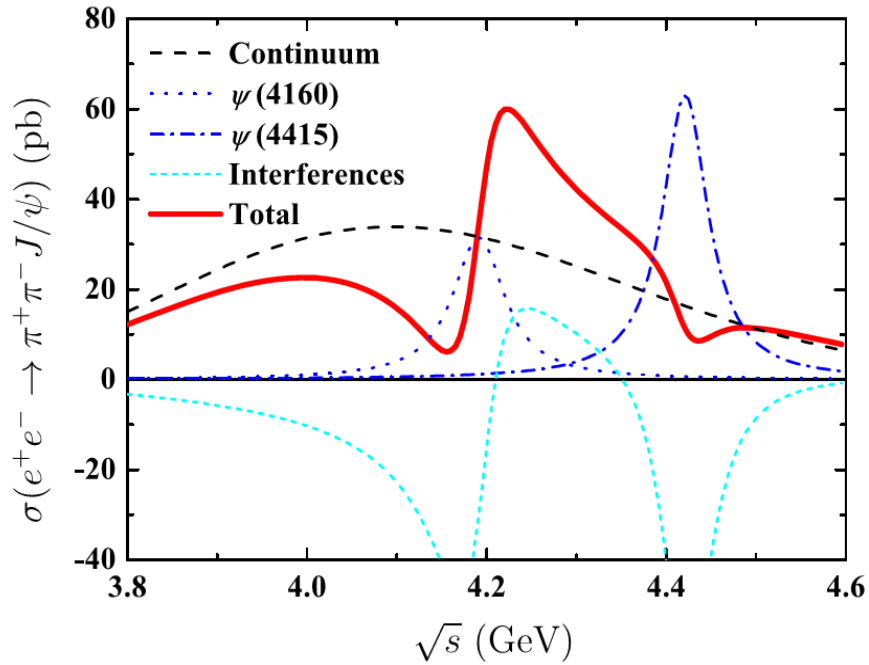
- The charmonium-like states $Y(4260)$ and $Y(4360)$ are sandwiched by charmonium states $\boldsymbol{\psi(4160)}$ **and** $\boldsymbol{\psi(4415)}$, thus we take these two states into present consideration.



Fitting to $e^+e^- \to \pi^+\pi^- J/\psi$

Chen, Liu, Li, Ke, PRD93,014011





Parameters

$e^+e^- \to \pi^+\pi^- J/\psi$			
g	(49.1 ± 3.6) GeV^{-1}	a	(1.9 ± 0.1) GeV^{-2}
$\mathcal{R}_{\psi(4160)}$	(2.6 ± 0.7) eV	ϕ_1	(6.0 ± 0.1) rad
$\mathcal{R}_{\psi(4415)}$	(5.2 ± 0.7) eV	ϕ_2	(4.4 ± 0.1) rad

χ^2/ndf=38.0/35

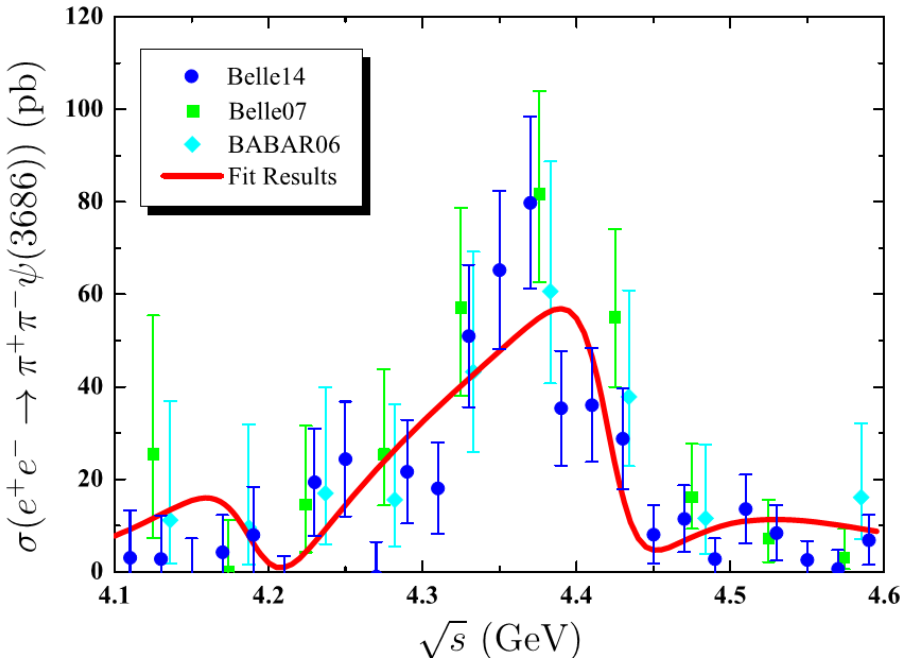
$$R_\psi \equiv \Gamma_\psi^{e^+e^-} \mathrm{BR}(\psi \to \pi^+\pi^- J/\psi)$$

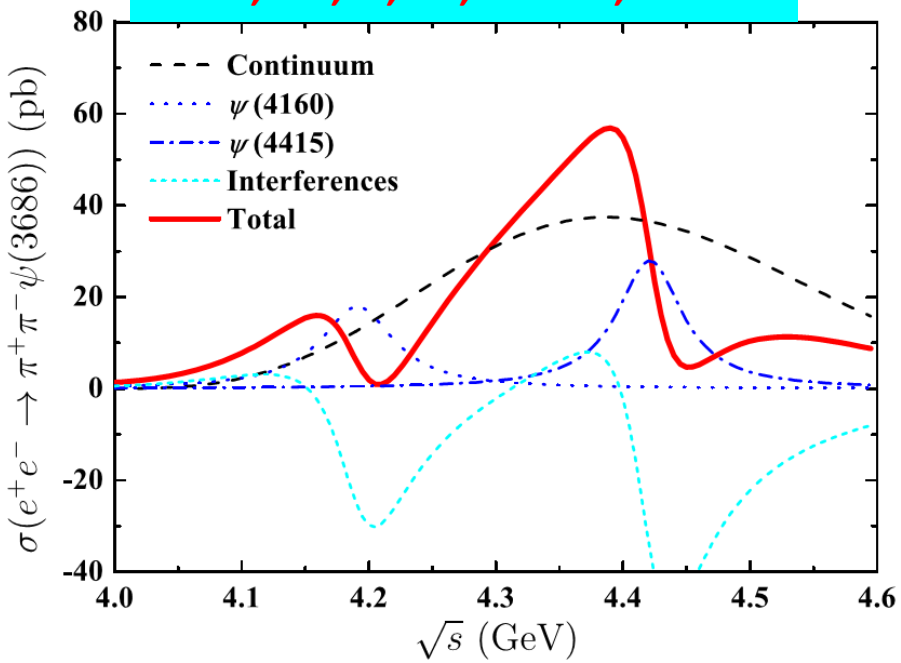
$$\mathbf{BR}[\psi(4160) \to \pi^+\pi^- J/\psi] = (5.4 \pm 3.9) \times 10^{-3}$$

$$\mathbf{BR}[\psi(4415) \to \pi^+\pi^- J/\psi] = (8.9 \pm 2.3) \times 10^{-3}$$

Fitting to $e^+e^- \to \pi^+\pi^-\psi(2S)$

Chen, Liu, Li, Ke, PRD93,014011





Parameters

$e^+e^- \to \pi^+\pi^-\psi(3686)$			
g	(150.6 ± 9.8) GeV^{-1}	a	(5.6 ± 0.7) GeV^{-2}
$\mathcal{R}_{\psi(4160)}$	(1.5 ± 0.8) eV	ϕ_1	(4.2 ± 0.2) rad
$\mathcal{R}_{\psi(4415)}$	(2.3 ± 0.8) eV	ϕ_2	(3.6 ± 0.2) rad

χ^2/ndf=42.0/25

$$\mathrm{BR}[\psi(4160) \to \pi^+\pi^-\psi(2S)] = (3.1 \pm 3.0) \times 10^{-3}$$

$$\mathrm{BR}[\psi(4415) \to \pi^+\pi^-\psi(2S)] = (4.0 \pm 1.9) \times 10^{-3}$$

Summary

- **The $Y(4008)$, $Y(4260)$ and $Y(4360)$ are not real resonance.**
  Fano-interferences between the continuum and the resonances
- **Naturally explain the absences of these states in open charm process and R-value scan (Need more data!).**
- **The branching ratios are fitted to be:**

$$\mathrm{BR}[\psi(4160) \to \pi^+\pi^- J/\psi] = (5.4 \pm 3.9) \times 10^{-3}$$
$$\mathrm{BR}[\psi(4415) \to \pi^+\pi^- J/\psi] = (8.9 \pm 2.3) \times 10^{-3}$$
$$\mathrm{BR}[\psi(4160) \to \pi^+\pi^- \psi(2S)] = (3.1 \pm 3.0) \times 10^{-3}$$
$$\mathrm{BR}[\psi(4415) \to \pi^+\pi^- \psi(2S)] = (4.0 \pm 1.9) \times 10^{-3}$$

- **Such interferences may also appear in some other process, such as $e^+e^- \to \pi^+\pi^-\psi(3770)$, K^+K^-J/ψ process.**

Thank you!

Backup