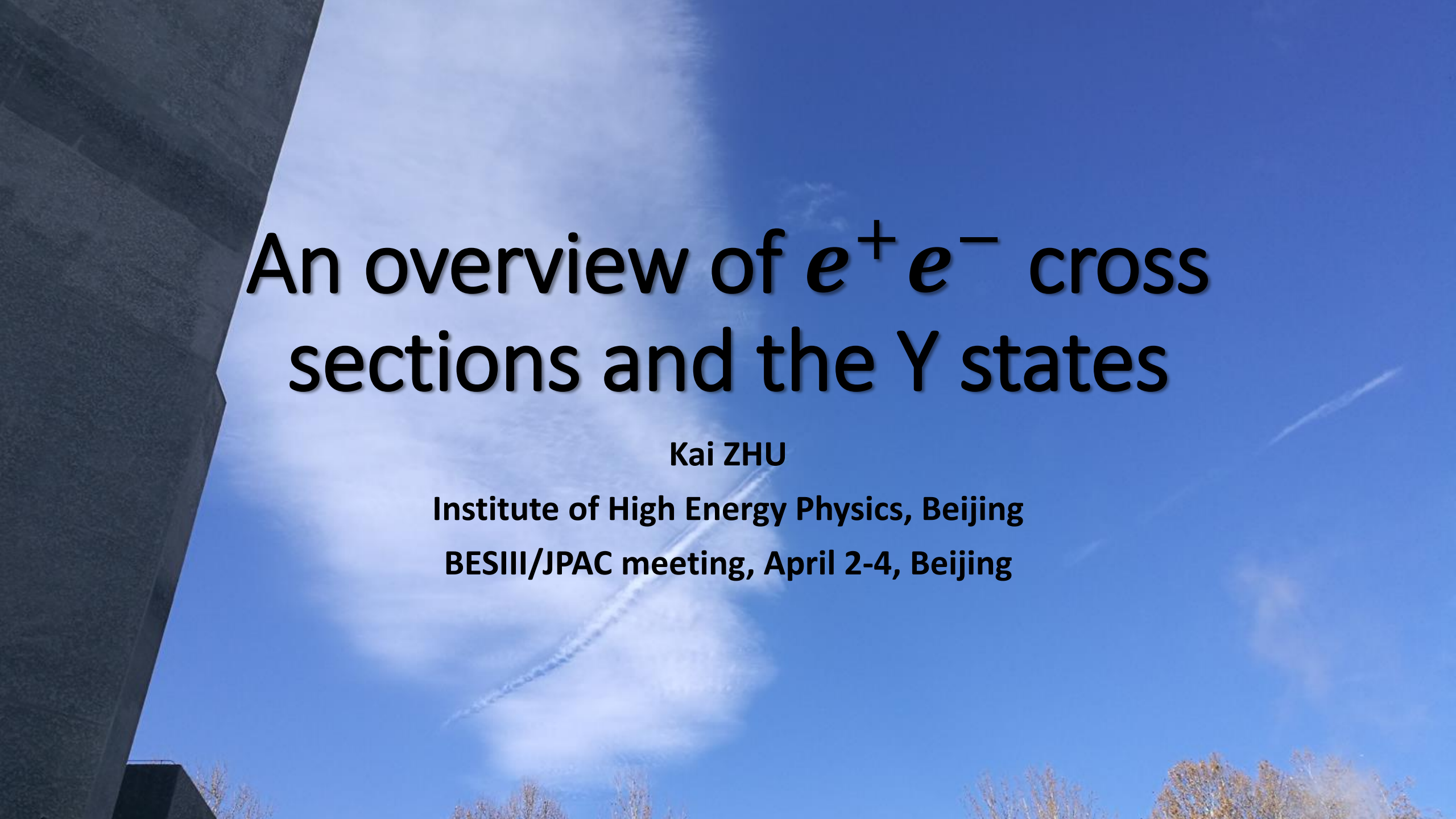


An overview of e^+e^- cross sections and the Y states

Kai ZHU

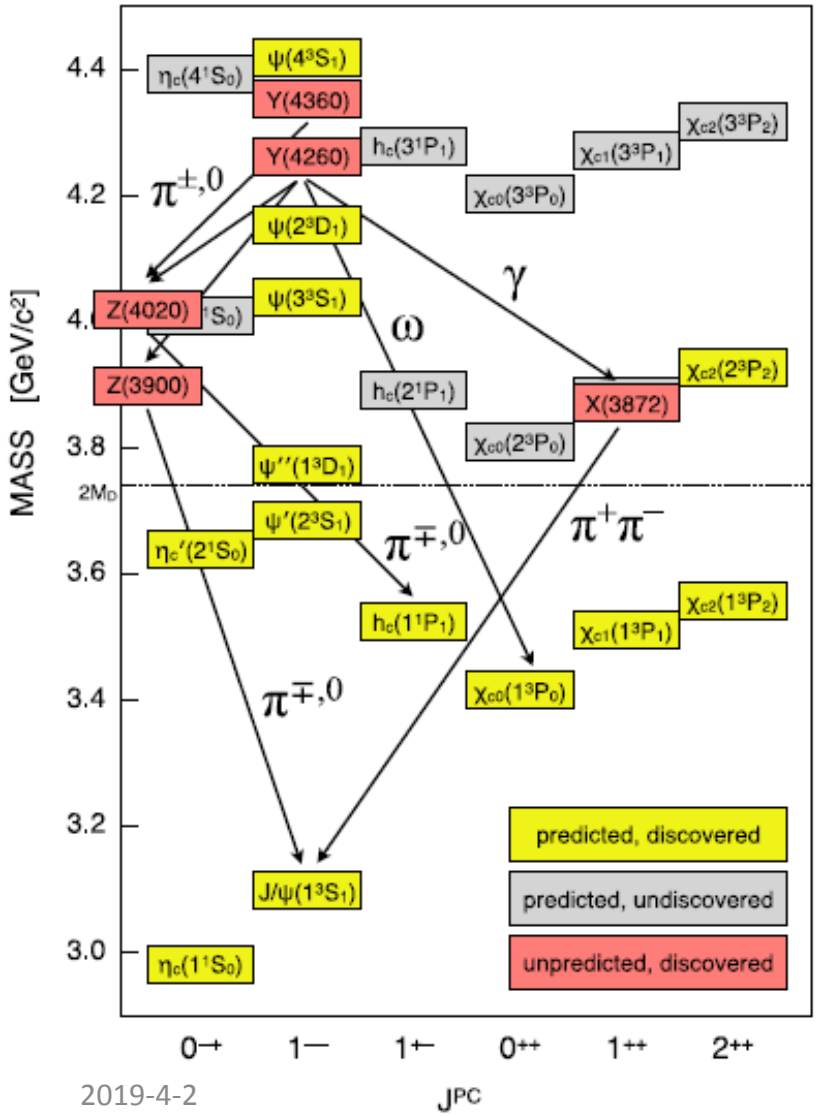
Institute of High Energy Physics, Beijing

BESIII/JPAC meeting, April 2-4, Beijing

Outline

- Recent BESIII results of e^+e^- cross sections and Y states
- Some properties of Y(4260)
- Problems in interpretation of the experimental results
- Summary

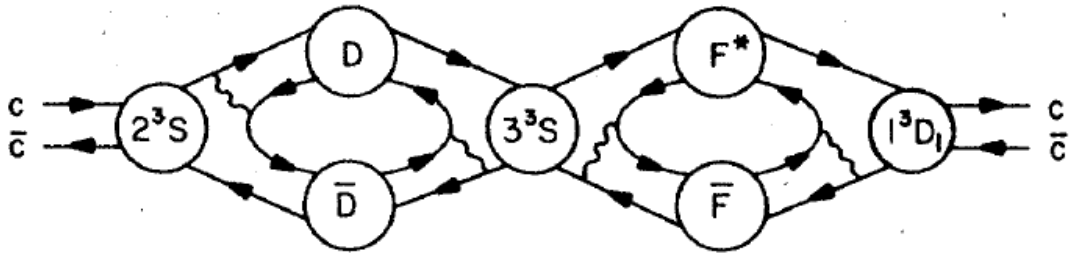
From 4.0 to 4.6 GeV, only four 1^{--} states predicted by potential model



ABOVE open charm threshold BELOW

Coupled channel effect

E. Eichten, etc., PRD 17 (1978) 11, PRD 21 (1980) 1



- New results due to updated parameters (**mass shift**)
- States **mixing** is usual due to coupled channel effect

$$|\psi'\rangle = \sum_n a_n |n^3S(c\bar{c})\rangle + \sum_n b_n |n^3D_1(c\bar{c})\rangle$$

$$+ \alpha |D\bar{D}; p\text{-wave}\rangle + \beta |D^*\bar{D}^*; f\text{-wave}\rangle + \cdots$$

Exotics in Leptonic Machines

Kai Zhu
Institute of High Energy Physics, Beijing
25–30 May 2014, FPCP, Marseille

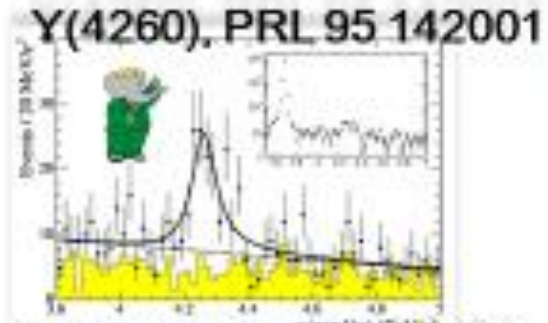
A slide in 2014

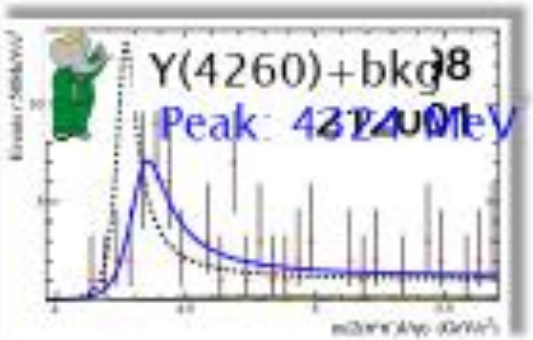
- **No evidence in the inclusive e^+e^- cross section, which only present $\psi(3770), \psi(4040), \psi(4160)$ $\psi(4415)$ [PLB 660,315]**

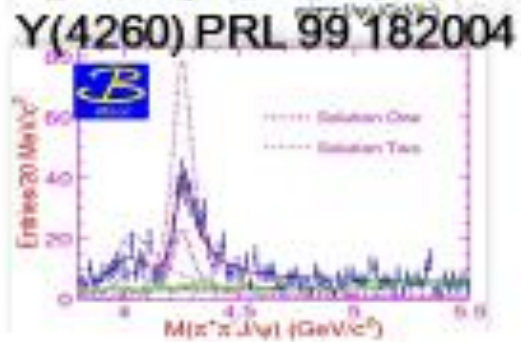
- **Most results from BaBar & Belle**

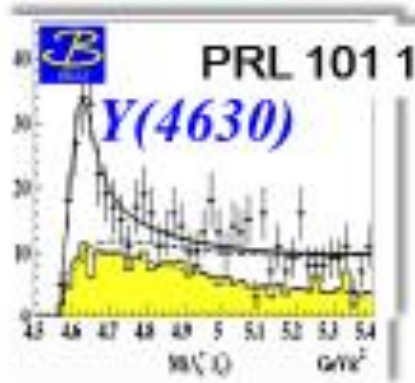
- **Much progress since then, many contributions from BESIII, update information**

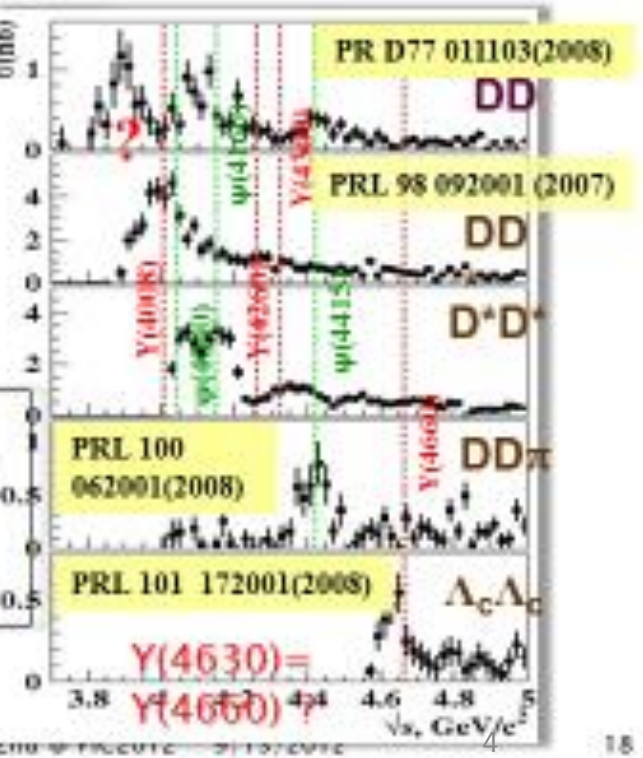
Y states: 1^{--} states from ISR











Too many Y states!

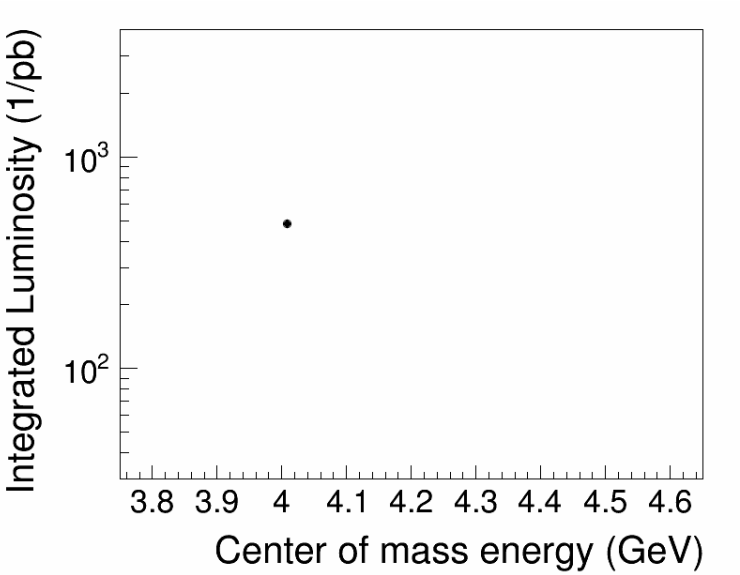
Y(4008)
Y(4260)
Y(4360)
Y(4660)
Y(4630)

Large partial width to $\pi^+\pi^- J/\psi$ and $\pi^+\pi^-\psi(2S)$

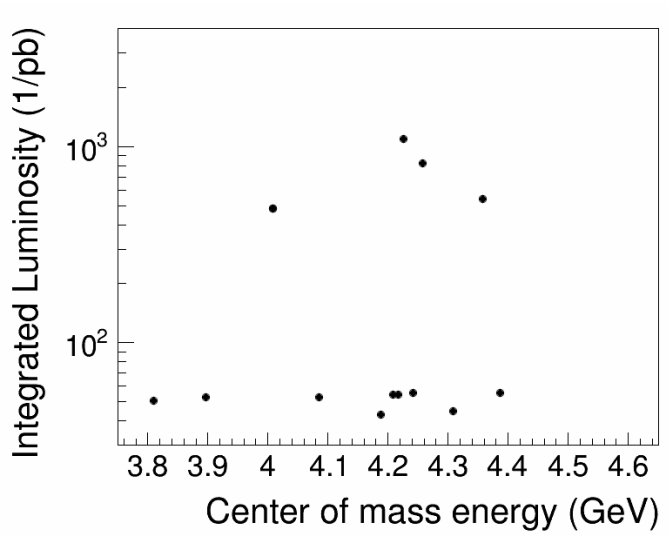
No sign of $Y \to D^{(*)}D^{(*)}$

Study e^+e^- annihilation line-shape above open charm threshold at BESIII

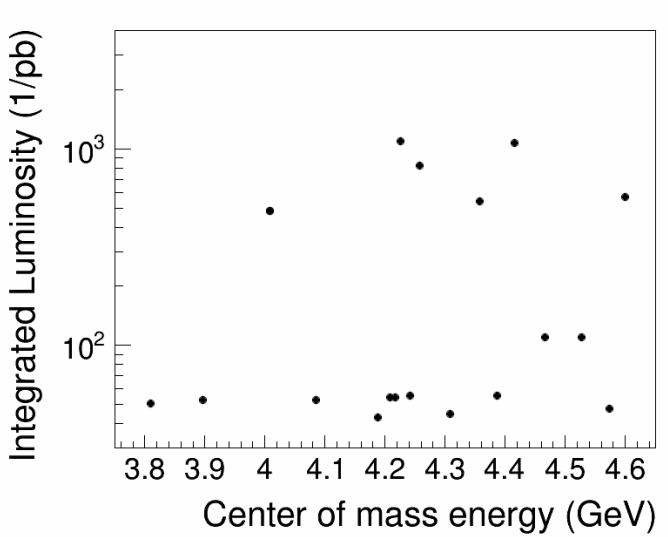
XYZ data sets at BESIII



2011



2013

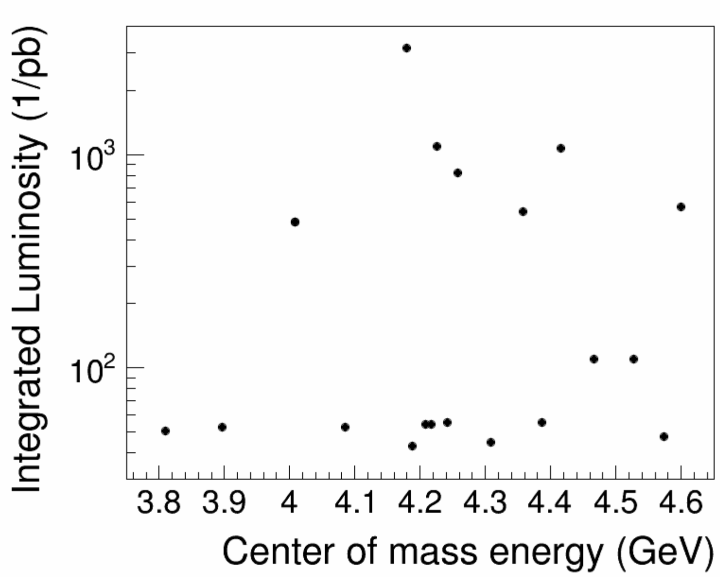


2014

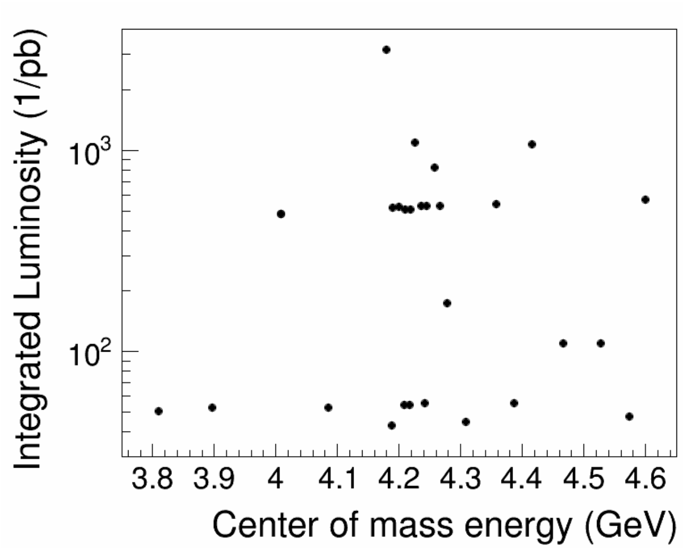
Study e^+e^- annihilation line-shape above open charm threshold at BESIII

XYZ data sets at BESIII

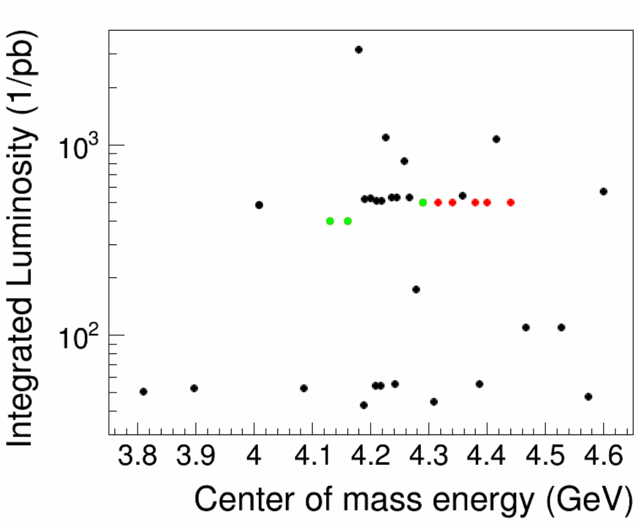
First three points finished



2016



2017



2019

Totally 13(before)+3.8(2019) fb^{-1} expected

Systematic studies of the e^+e^- annihilation line-shape above open charm threshold at BESIII

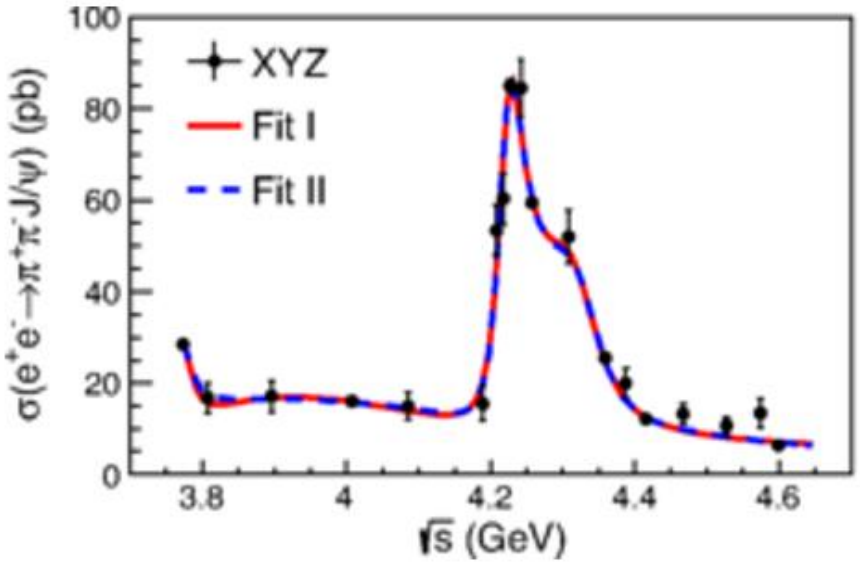
- Hidden charm
- Open charm
- Light hadrons

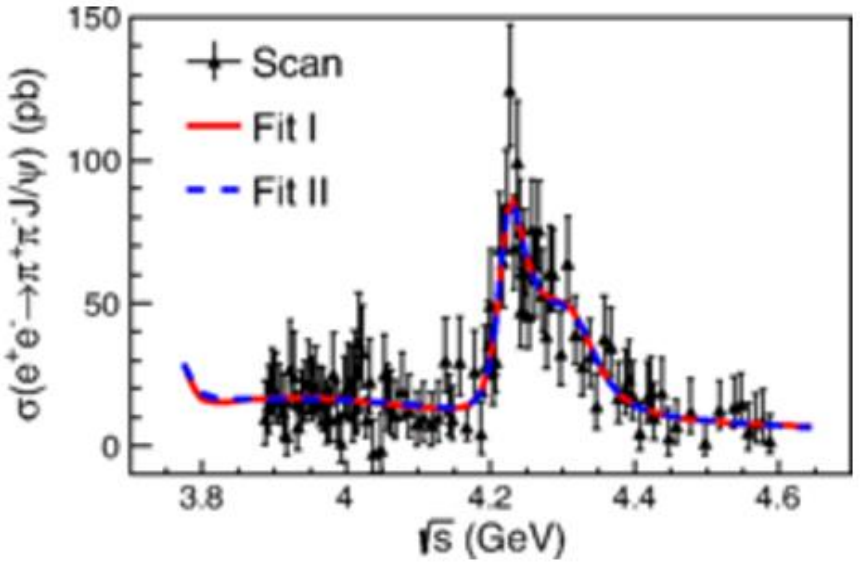
Y(4260) and Y(4360) are observed in

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

Y(4008) is not confirmed

PRL 118, 092001 (2017)





Y(4220) [in MeV]

Mass: $4222.0 \pm 3.1 \pm 1.4$

Width: $44.1 \pm 4.3 \pm 2.0$

Y(4320) [in MeV]

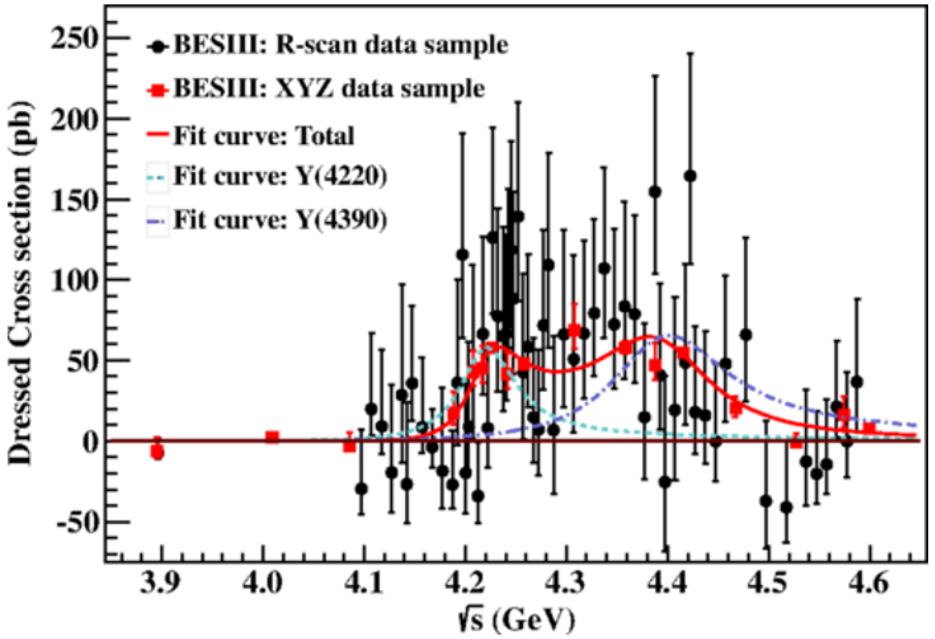
Mass: $4320.0 \pm 10.4 \pm 7.0$

width: $101.4^{+25.3}_{-19.7} \pm 102$

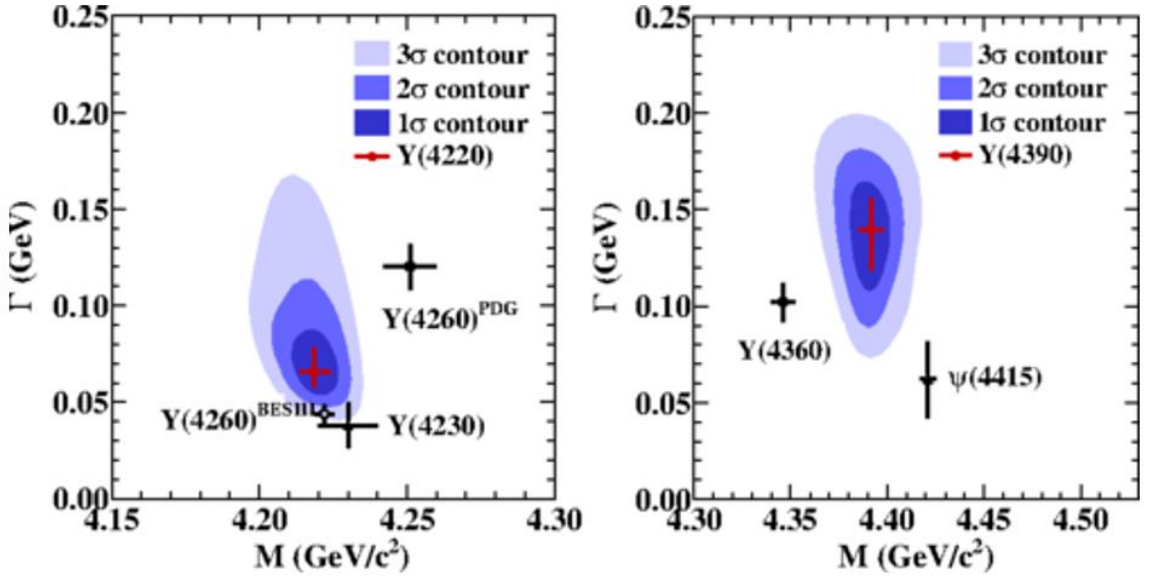
7.5σ

Observed first time in this channel, consistent with Y(4360) observed in BaBar and Belle

Observation of Y(4390) in $e^+e^- \to \pi^+\pi^- h_c$ PRL 118, 092002 (2017)



Observation of Y(4390) in $e^+e^- \to \pi^+\pi^- h_c$ PRL 118, 092002 (2017)



Y(4220) in [MeV]

Mass: $4218.4^{+5.5}_{-4.5} \pm 0.9$

Width: $66.0^{+12.3}_{-8.3} \pm 0.4$

$\Gamma_{ee}B = 4.6^{+2.9}_{-1.4} \pm 0.8$ eV

Y(4390) in [MeV]

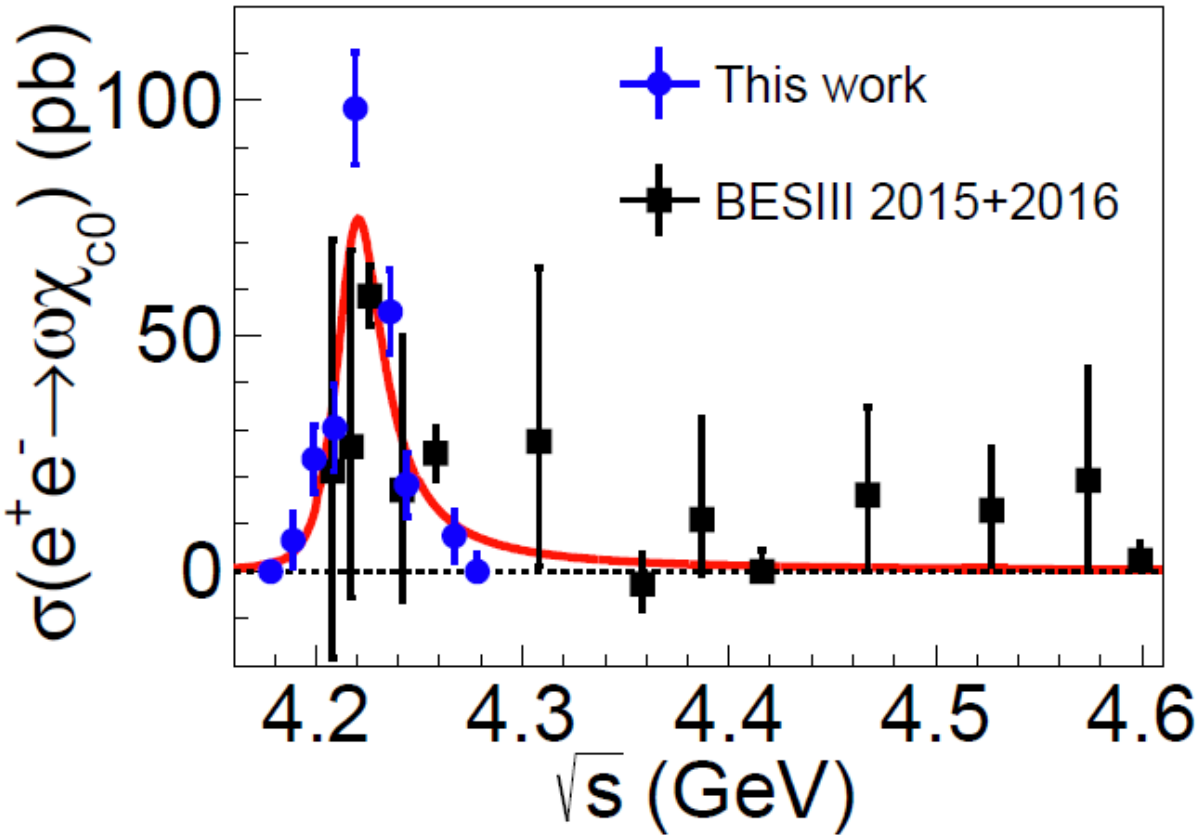
Mass: $4391.5^{+6.3}_{-6.8} \pm 1.0$

Width: $139.5^{+16.2}_{-20.6} \pm 0.6^{+12.3}_{-8.3}$

$\Gamma_{ee}B = 11.6^{+5.0}_{4.4} \pm 1.9$ eV

Total: 10σ

arXiv:1903.02359, update of PRL 114, 092003(2015)



$\chi_{c0} \to KK/\pi\pi$

Y(4220) [in MeV]

Mass: $4218.5 \pm 1.6 \pm 4.0$

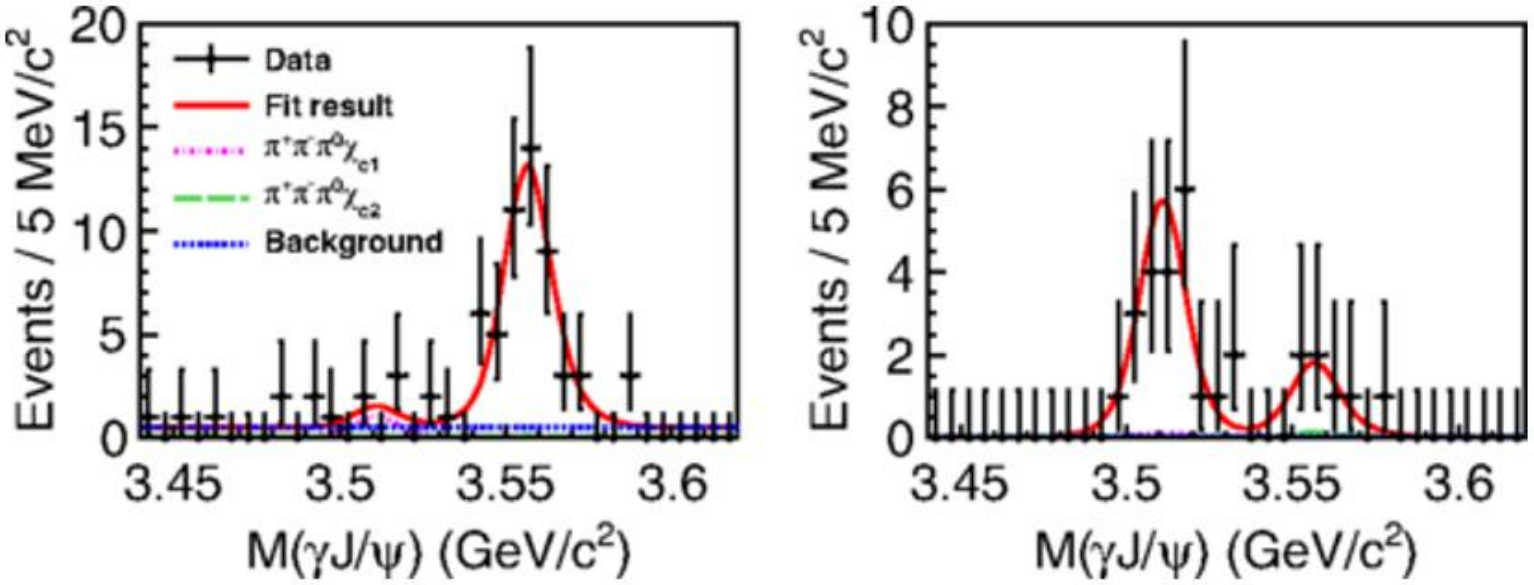
Width: $28.2 \pm 3.9 \pm 1.6$

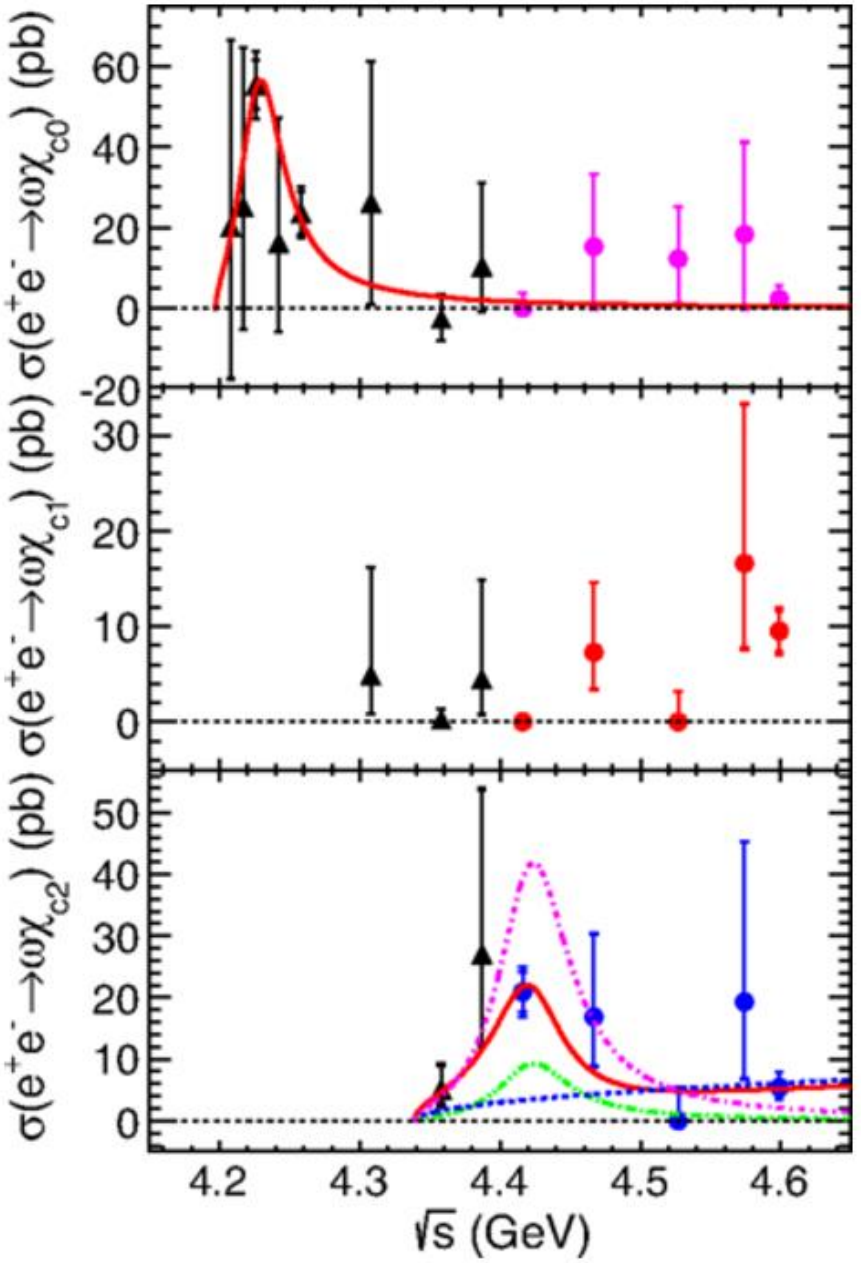
$\Gamma_{ee}B = 2.5 \pm 0.2 \pm 0.3$ eV

$\alpha = -0.30 \pm 0.18 \pm 0.05$

Combination of S and D waves

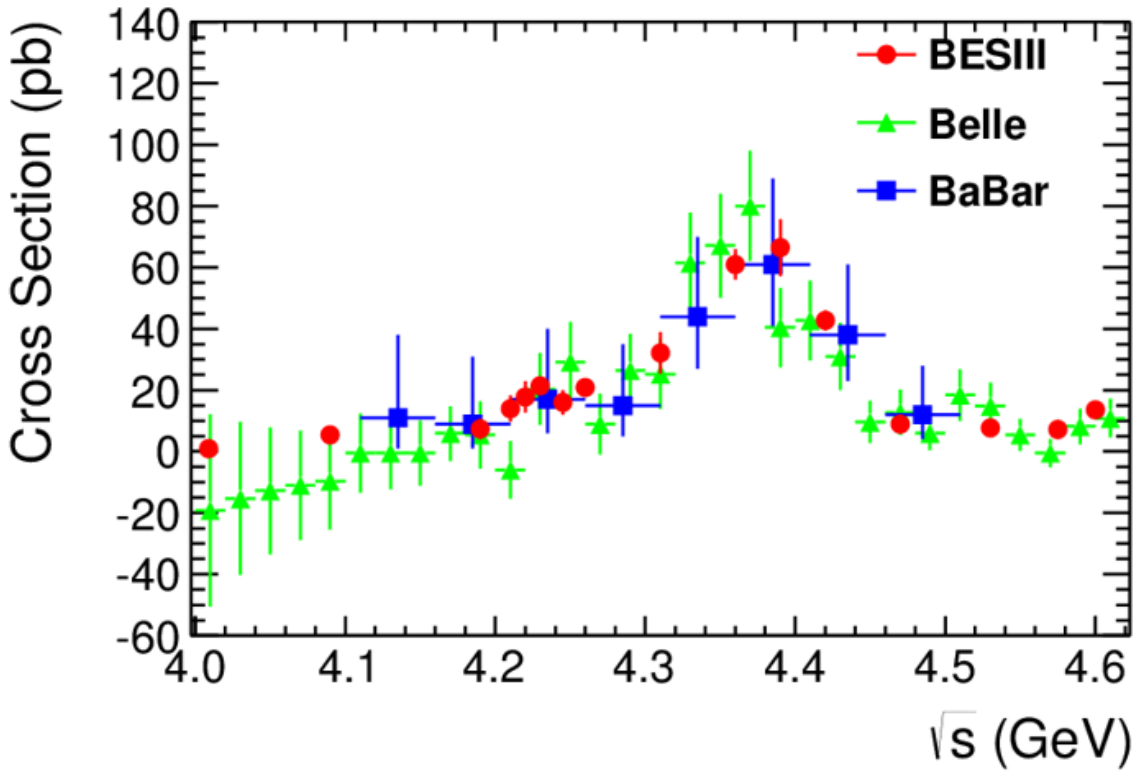
Clear signals of $e^+e^-\omega\chi_{c1,2}$ are observed at $\sqrt{s} > 4.4$ GeV PRD 93, 011102(R) (2016)





- Enhancement of $\omega\chi_{c2}$ around 4.42 GeV, $B(\psi(4415) \to \omega\chi_{c2})$ in the order of 10^{-3}
- $\omega\chi_{c1}$ seems rising at 4.6 Gev

Cross section of $e^+e^- \to \pi^+\pi^-\psi'$ Phys. Rev. D 96, 032004 (2017)



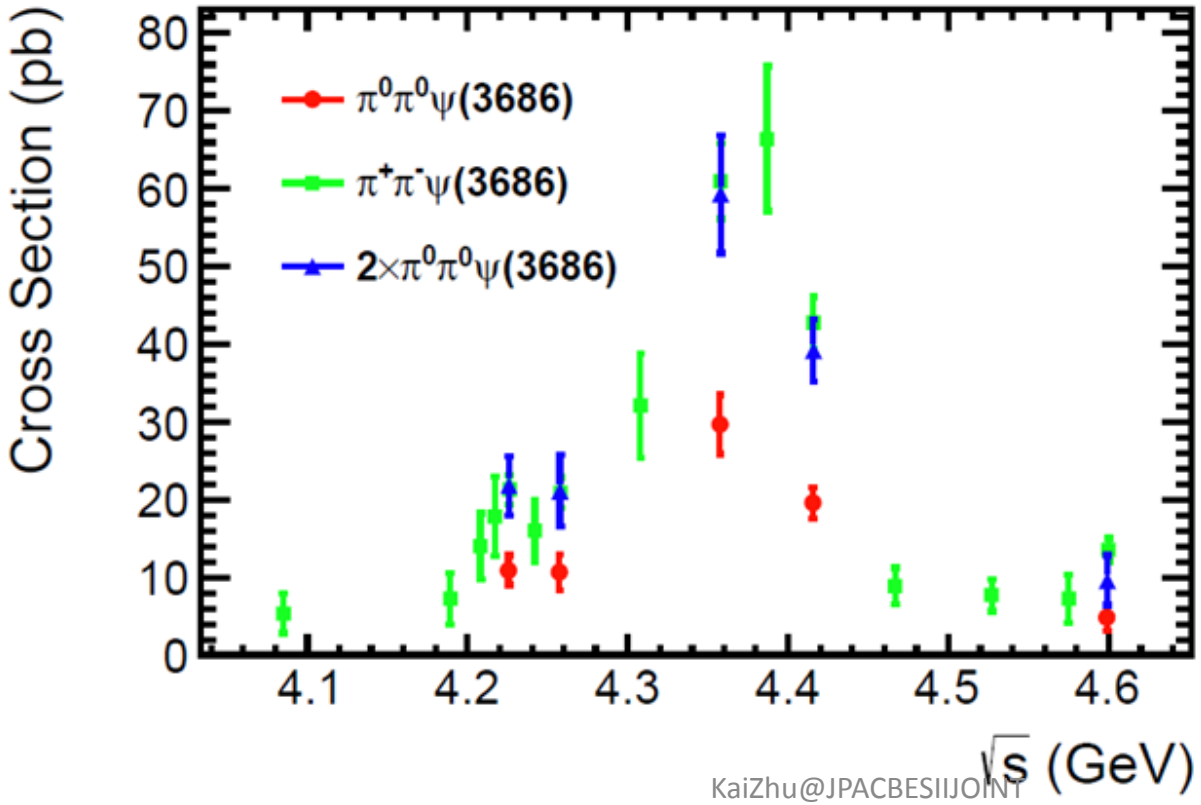
PRD 99, 019903 (E) (2019)

Y(4220) [in MeV]
Mass: $4209.5 \pm 7.4 \pm 1.6$
Width: $80.1 \pm 24.6 \pm 2.9$
$\Gamma_{ee}B = 1.61 \pm 1.27$ eV
or 1.80 ± 1.41 eV

Y(4390) [in MeV]
Mass: $4383.8 \pm \pm$
Width: $84.2 \pm 12.5 \pm 2.1$
$\Gamma_{ee}B = 7.25 \pm 2.8$ eV
or 10.96 ± 3.8 eV

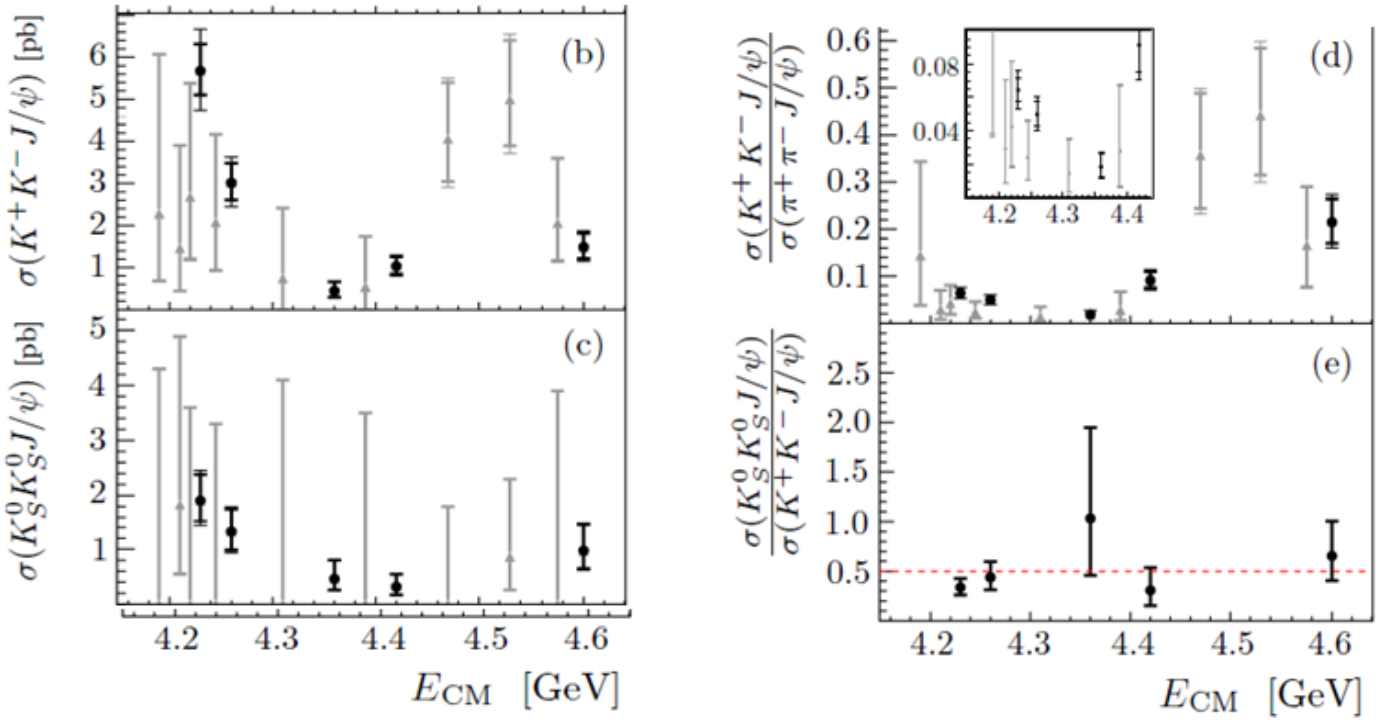
Note: two solutions

Cross sections and neutral structure in $e^+e^- \to \pi^0\pi^0\psi(3686)$ Phys. Rev. D 97, 052001 (2018)



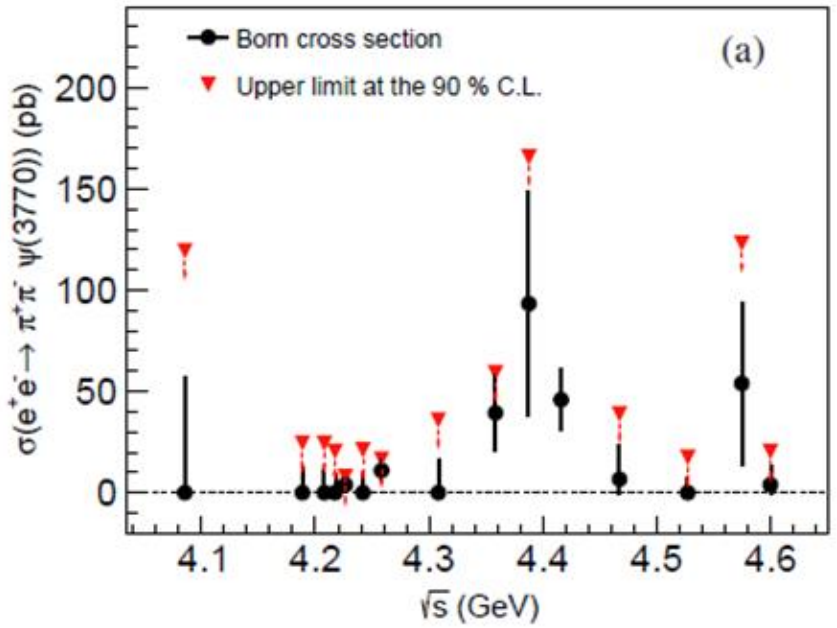
Cross sections are half of the charged mode.

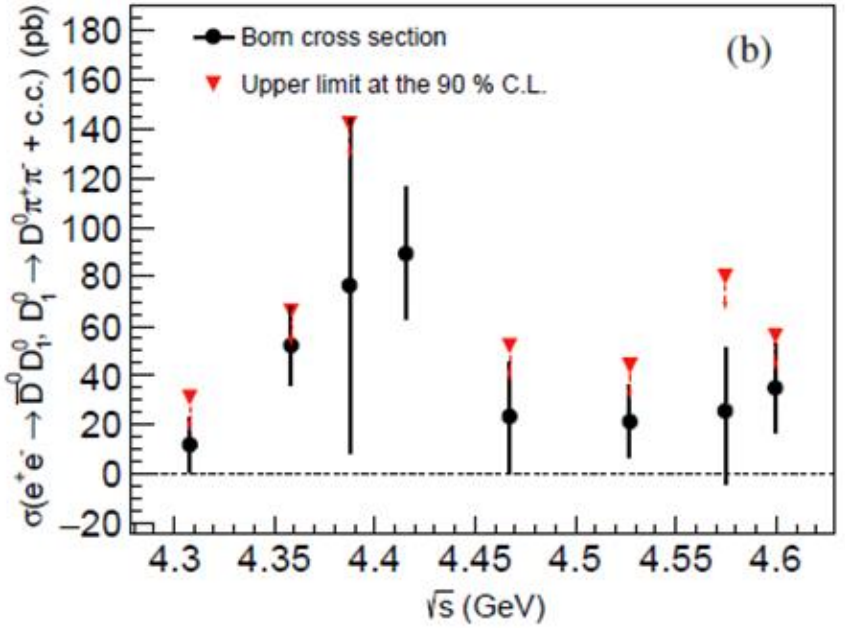
Structures in the line-shape of $e^+e^- \to KKJ/\psi$ Phys. Rev. D 97, 071101(R) (2018)



Observation of $e^+e^- \to \pi^+\pi^-\psi(3770)$ and $D_1(2420)^0\overline{D}^0$ + c.c.

arXiv:1903.08126, submitted to PRD





$e^+e^- \to \pi^+\pi^-\psi(3770)$ (a), $e^+e^- \to D_1(2420)^0\bar{D}^0 \to \pi^+\pi^- D^0\bar{D}^0$ (b).

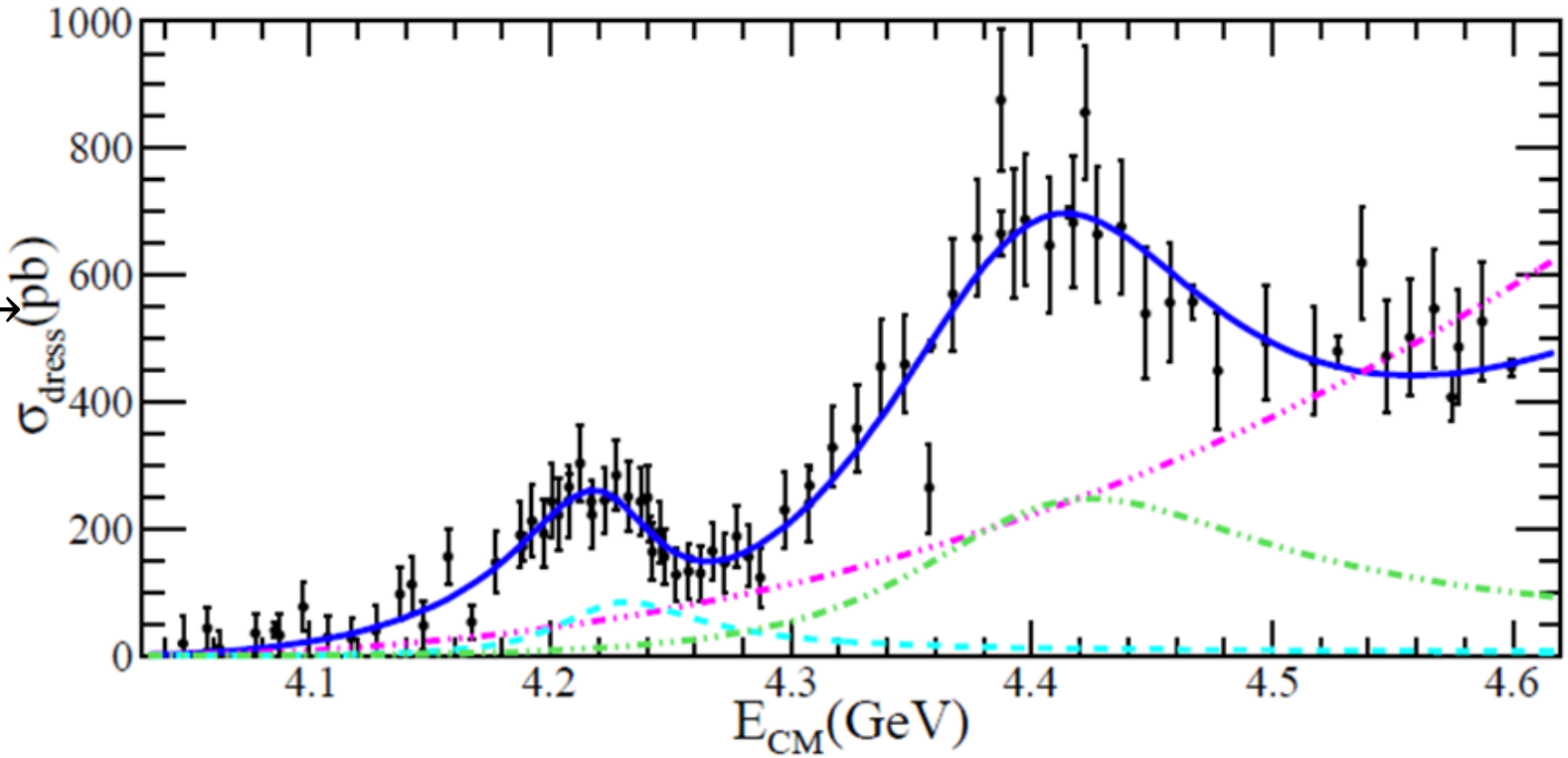
Observation at 4.42 GeV, evidence at 4.26 and 4.36 GeV

Observation of Y(4220) in $e^+e^- \to \pi^+ D^0 D^{*-}$ cross sections
Phys. Rev. Lett. 122, 102002 (2019)

Y(4220) [in MeV]
Mass: $4228.6 \pm 4.1 \pm 5.9$
Width: $77.1 \pm 6.8 \pm 6.9$

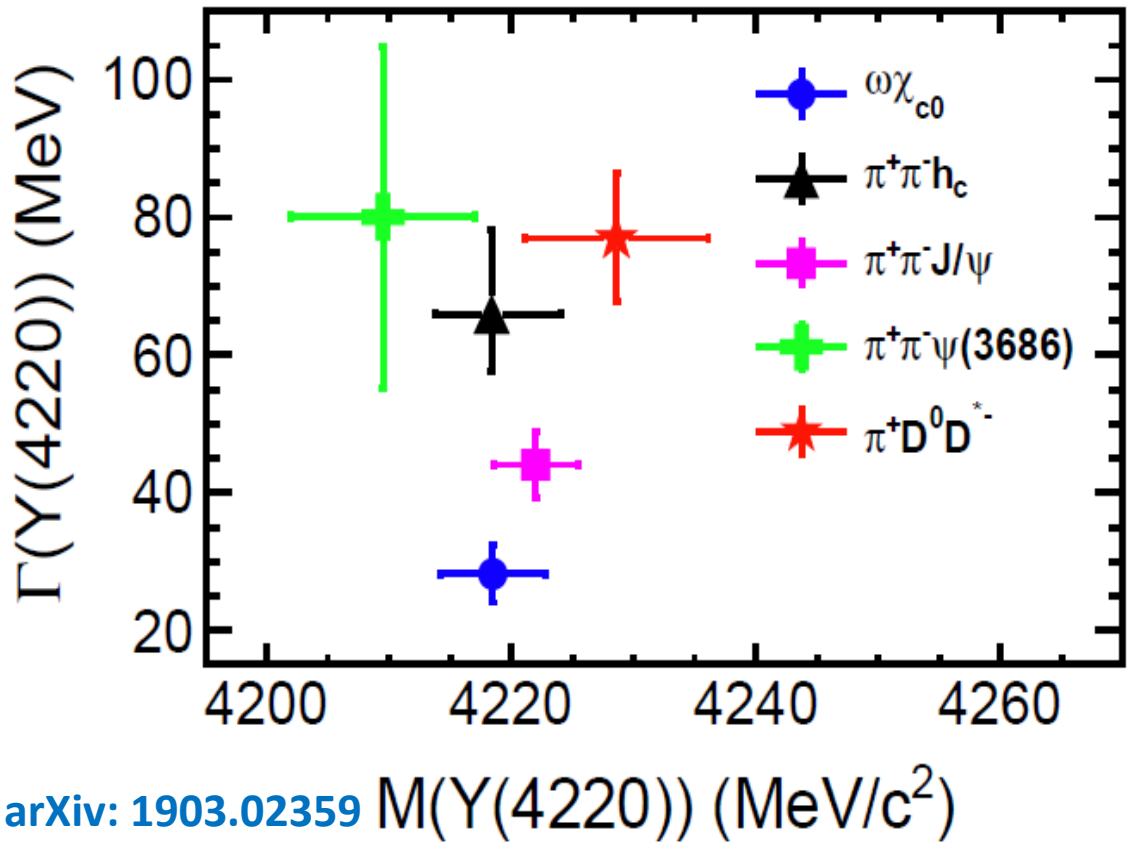
First open charm evidence of Y(4220) decay

Belle has observed $\psi(4415) \to D\bar{D}_2^*(2460)$ PRL 100, 062001
But a single $\psi(4415)$ cannot describe the enhancement around 4.4 GeV

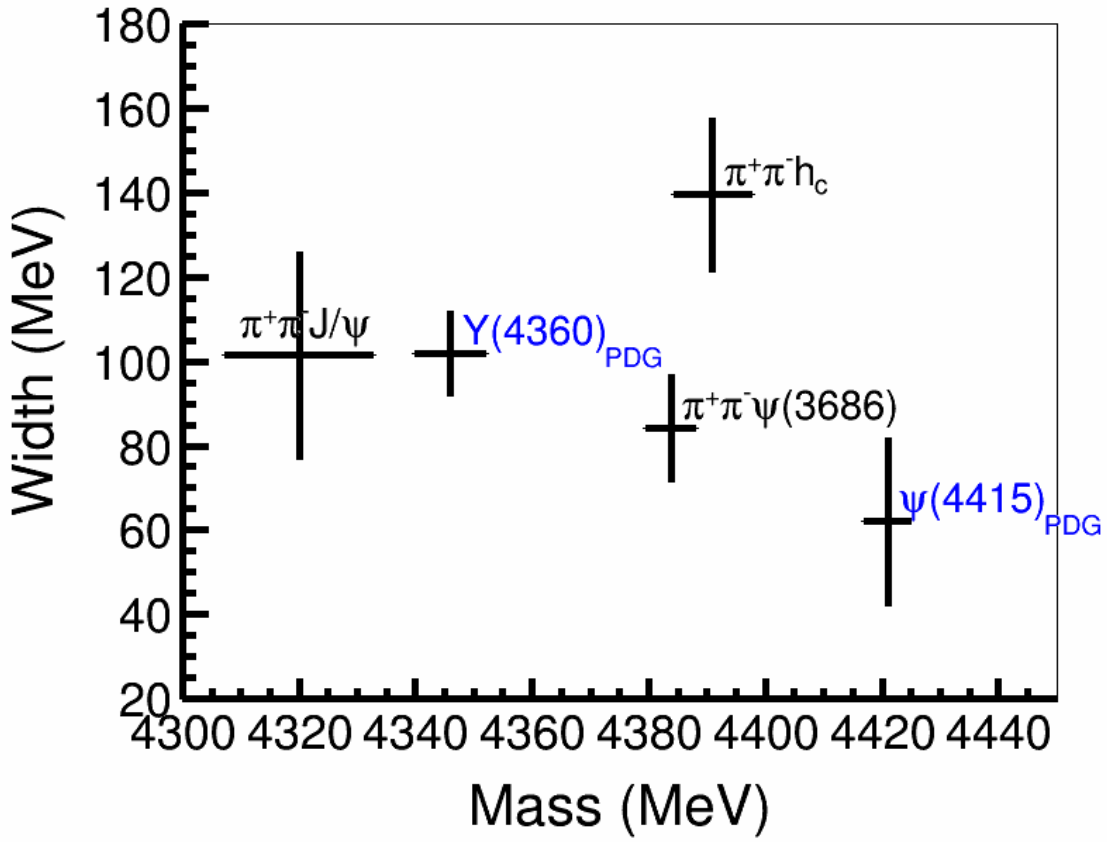


Mass shift from Y(4260) to Y(4220) Y(4320)/Y(4360)/Y(4390)?

Y(4260) PDG



arXiv: 1903.02359



No observations of light hadron final states

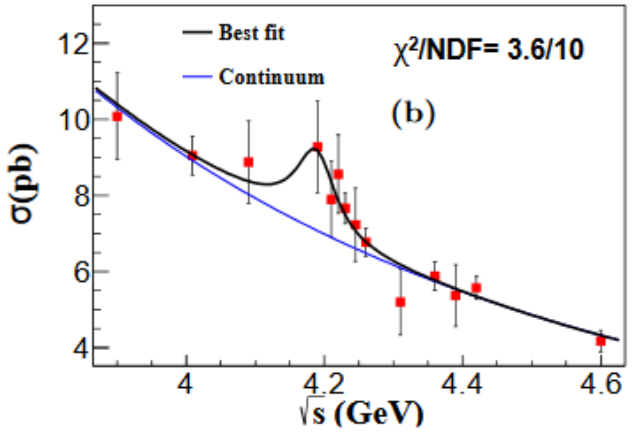
$e^+e^- \to K_S K^\pm K^\mp \pi^0$

product $\Gamma_{e^+e^-}\mathcal{B}\ (Y(4260) \to K_S^0 K^\pm \pi^\mp \pi^0)$ at 90% C.L. are estimated to be less than 0.05 eV and that of $\Gamma_{e^+e^-}\mathcal{B}(Y(4260) \to K_S^0 K^\pm \pi^\mp \eta)$ is estimated to be smaller than 0.19 eV. Reference [9] reported four solutions of the product $\Gamma_{e^+e^-}\mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi)$, in which the maximum is 13.3 ± 1.4 eV and the minimum is 1.5 ± 0.3 eV.

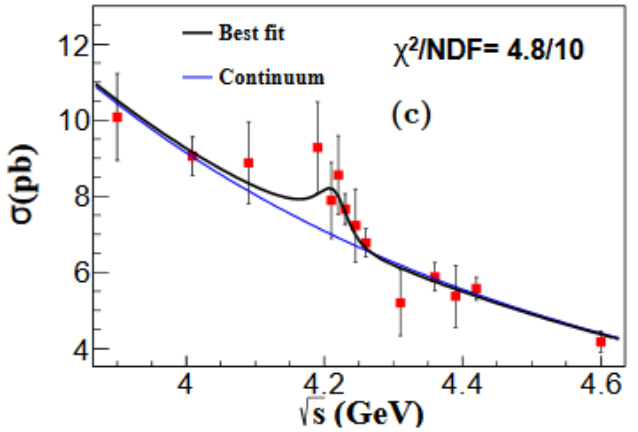
PHYSICAL REVIEW D **99,** 012003 (2019)

	$\psi(4160)$		$Y(4220)$	
	Solution I	Solution II	Solution I	Solution II
$\Gamma_{ee} \times B_{K_S^0 K^+\pi^-}$ (eV)	2.71±0.13	0.0118±0.0098	2.03±0.05	0.0038±0.0029
ϕ (rad)	-1.60±0.03	1.71±0.38	-1.61±0.02	2.11±0.43
Significance	2.8σ		2.6σ	

$e^+e^- \to K_S K^\pm K^\mp \pi^0$

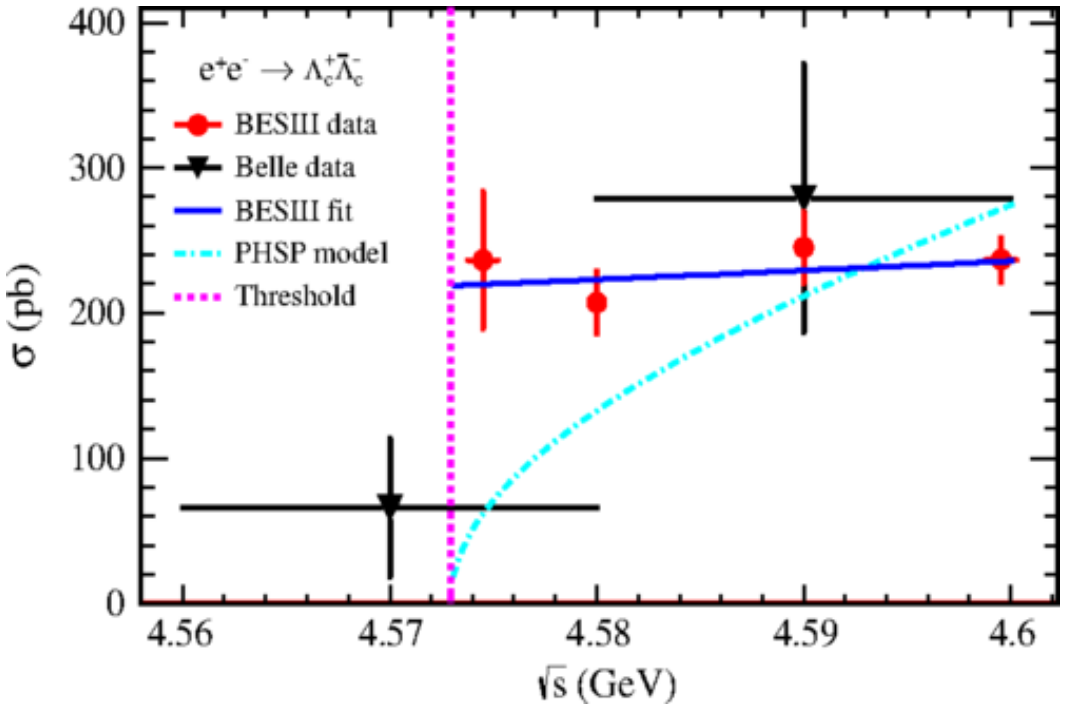


arXiv: 1808.08733, Accepted by PRD



$e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ near threshold

Phys. Rev. Lett. 120, 132001 (2018)

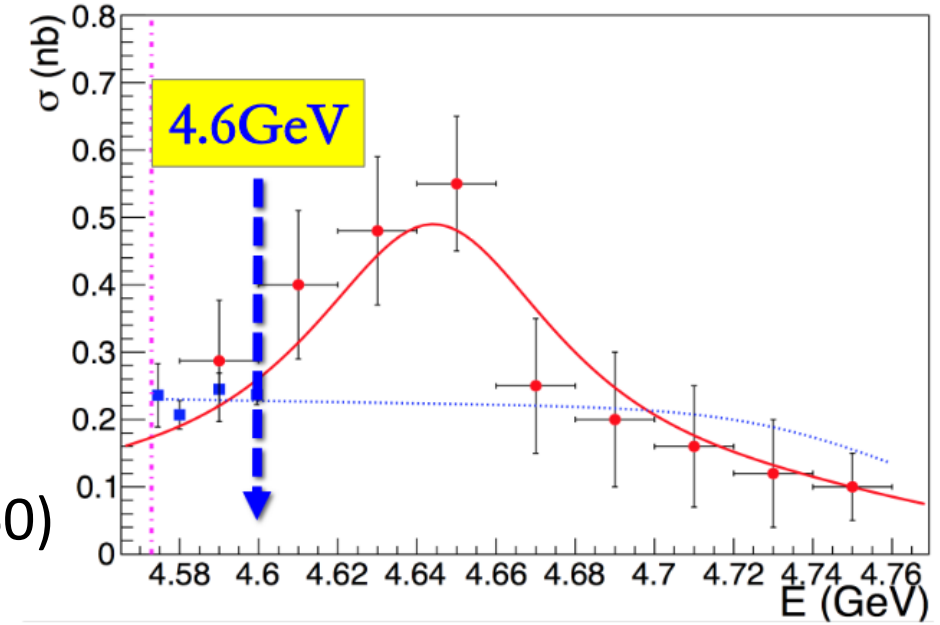


√s=**4574.5**, 4580.0, 4590.0 and **4599.5** MeV

$|G_E/G_M|$:

$\mathbf{1.14 \pm 0.14 \pm 0.07}$

$\mathbf{1.23 \pm 0.05 \pm 0.03}$



Will update BEPCII this summer to 4.9 GeV

Cross sections measurement of Λ_c pair

Check consistence with BELLE and search for Y(4660)

$e^+e^- \to \pi^+\pi^-\pi^0\eta_c$, new $Z_c(3900)$ decay mode

TABLE II: Born cross sections of $e^+e^- \to \pi^\mp Z_c(3900/4020)^\pm \to \pi^\mp\rho^\pm\eta_c$ (numbers for $Z_c(4020)^\pm$ are in brackets). The parameters are defined in the same way as those in Table I.

$\sqrt{s}$ (MeV)	$\mathcal{L}$ (pb^{-1})	$N_{\rm obs}$	$(1+\delta)$	$\frac{1}{\lvert 1-\Pi\rvert^2}$	$\sum\varepsilon_i\mathcal{B}_i$ (%)	$\sigma^{\rm B}$ (pb)	$\sigma^{\rm B}_{\rm U.L.}$ (pb)	$\mathcal{S}$ (σ)
4226.3	1091.7	240 ± 56 (21 ± 13)	0.74	1.056	0.60 (0.49)	$47 \pm 11 \pm 11$	< 75 (16)	4.3 (1.0)
4258.0	825.7	92 ± 47 (0 ± 15)	0.76	1.054	0.44 (0.51)	$32 \pm 16 \pm 9$	< 71 (9)	2.0 (...)
4358.3	539.8	12 ± 38 (0 ± 5)	1.03	1.051	0.46 (0.54)	$5 \pm 14 \pm 2$	< 34 (11)	0.3 (...)
4415.6	1073.6	101 ± 46 (6 ± 16)	1.15	1.053	0.69 (0.58)	$11 \pm 5 \pm 3$	< 23 (7)	2.2 (...)
4599.5	566.9	0 ± 5 (0 ± 10)	1.32	1.055	0.26 (0.24)	$0 \pm 3 \pm 2$	< 12 (18)	...

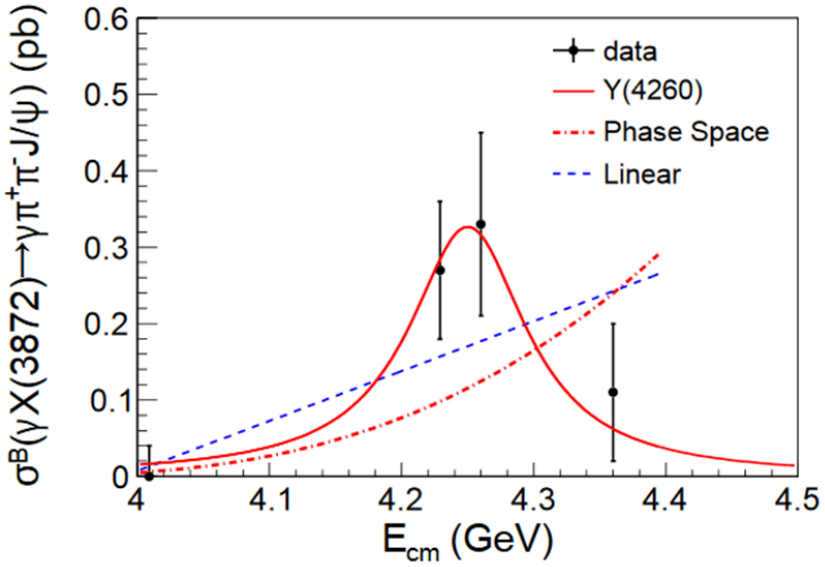
Relations between different channels @ Y(4220)

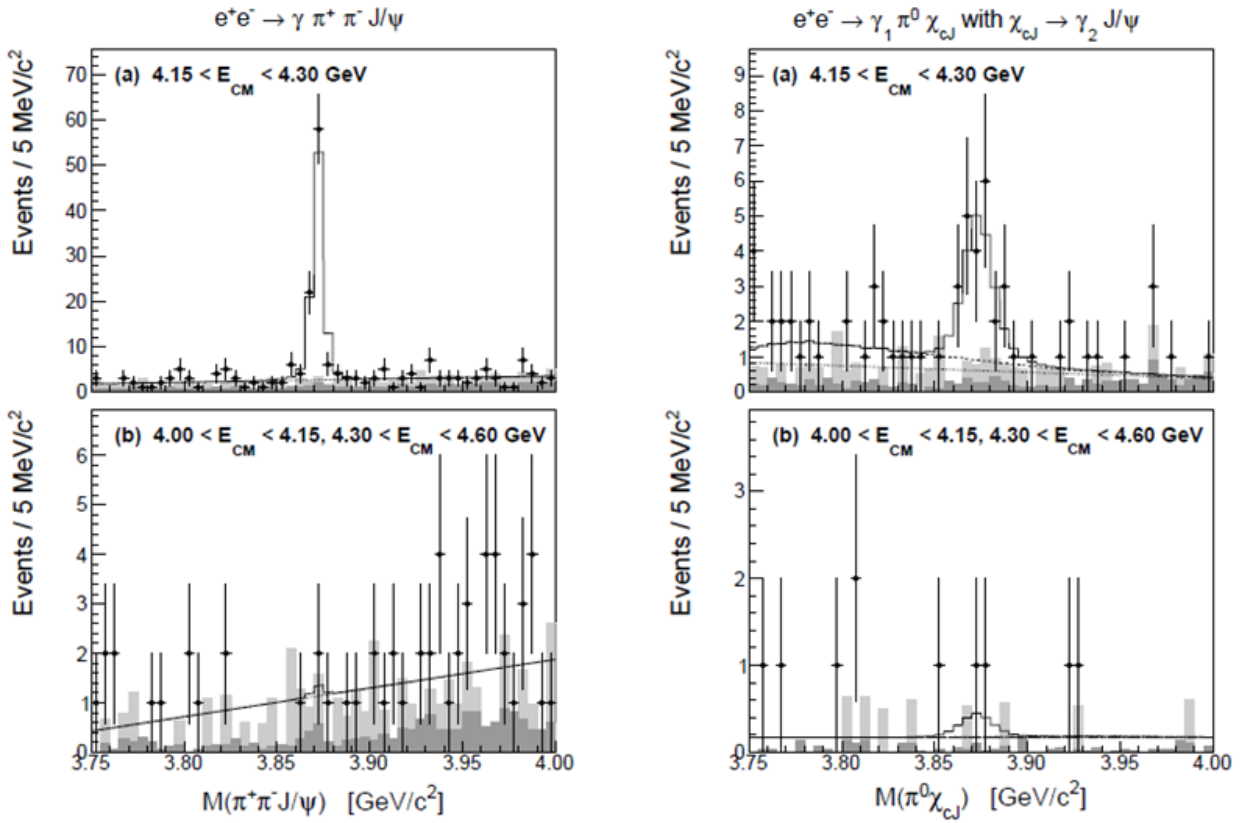
Channels	$\Gamma_{ee}B\ (eV)$	Note
$\pi^+\pi^- J/\psi$	1.6~13.3	Four solutions
$\pi^+\pi^- h_c$	$4.6^{+2.9}_{-1.4} \pm 0.8$	
$\omega\chi_{c0}$	$2.5 \pm 0.2 \pm 0.3$	
$\pi^+\pi^-\psi(3686)$	$1.61 \pm 1.27 (1.80 \pm 1.41)$	Two solutions
$K^+K^- J/\psi$	$R \approx 0.1$	Cross section ratio to $\pi^+\pi^- J/\psi$
$\pi^+\pi^-\pi^0\eta_c$	$R = 2.1 \pm 0.8$	
$\pi^+ D^0 D^{*-}$	$> \sum(hidden\ charm)$	
Light hadrons	< 0.1	Not observed

Connect between Y(4220) and X(3872)

$e^+e^- \to \gamma X(3872) \to \gamma\pi^0\chi_{c1}$
arXiv:1901.03992, submitted to PRL

$\sigma^B(e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$
PRL 112, 092001 (2014)



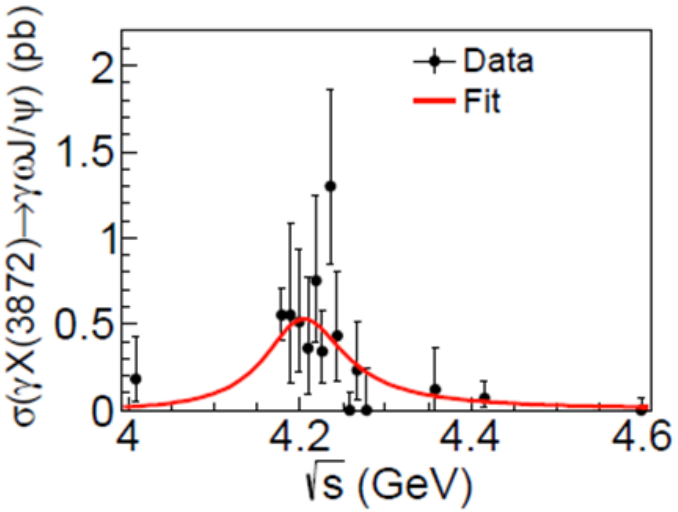


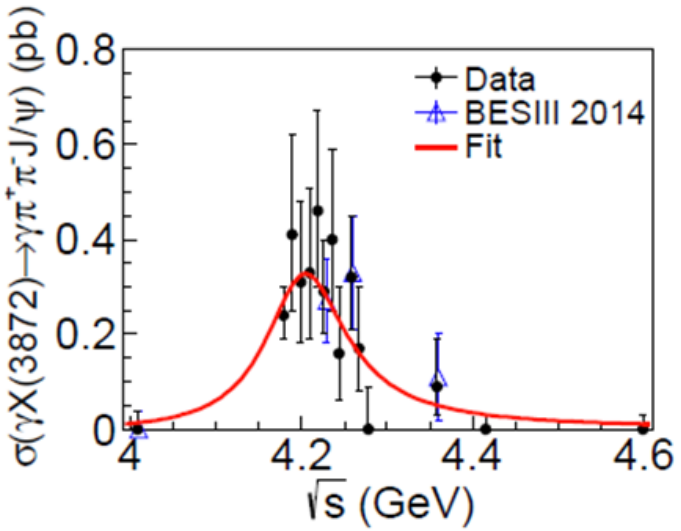
$$\frac{B[Y(4260) \to \gamma X(3872)]}{B[Y(4260) \to \pi^+\pi^- J/\psi]} = 0.1$$

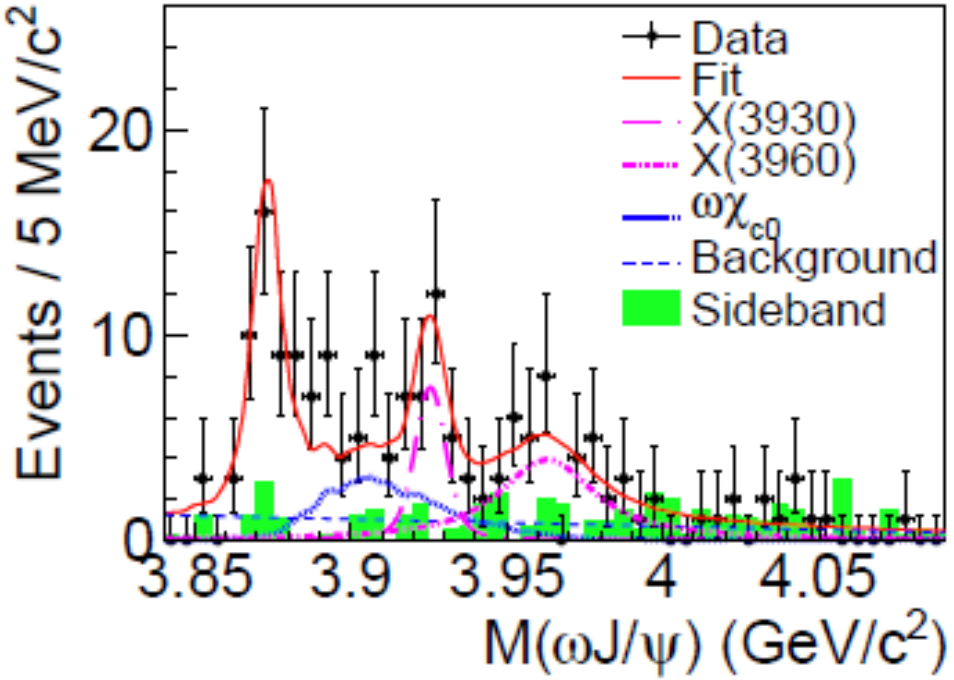
assuming $B[X(3872) \to \pi^+\pi^- J/\psi] = 5\%$

$$\frac{B[X(3872) \to \pi^0\chi_{c1}]}{B[X(3872) \to \pi^+\pi^- J/\psi]} = 0.88^{+0.33}_{-0.27} \pm 0.10$$

$e^+e^- \to \gamma X(3872) \to \gamma\omega J/\psi$
arXiv:1903.04695, submitted to PRL

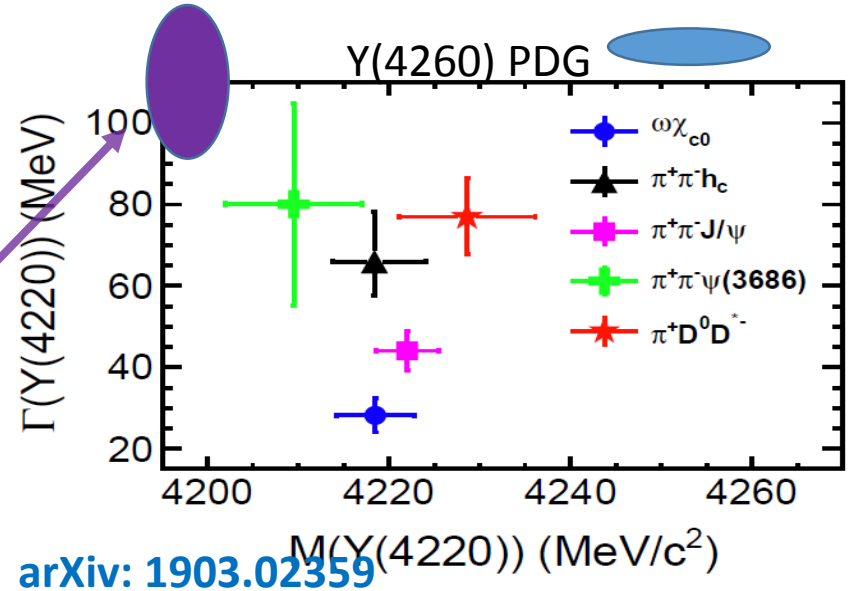






$$\frac{B[X(3872) \to \omega J/\psi]}{B[X(3872) \to \pi^+\pi^- J/\psi]} = 1.6^{+0.4}_{-0.3} \pm 0.2$$

Y(4200) M: $4200.6^{+7.9}_{-13.3} \pm 3.0$ Γ: $115^{+38}_{-26} \pm 12$ MeV



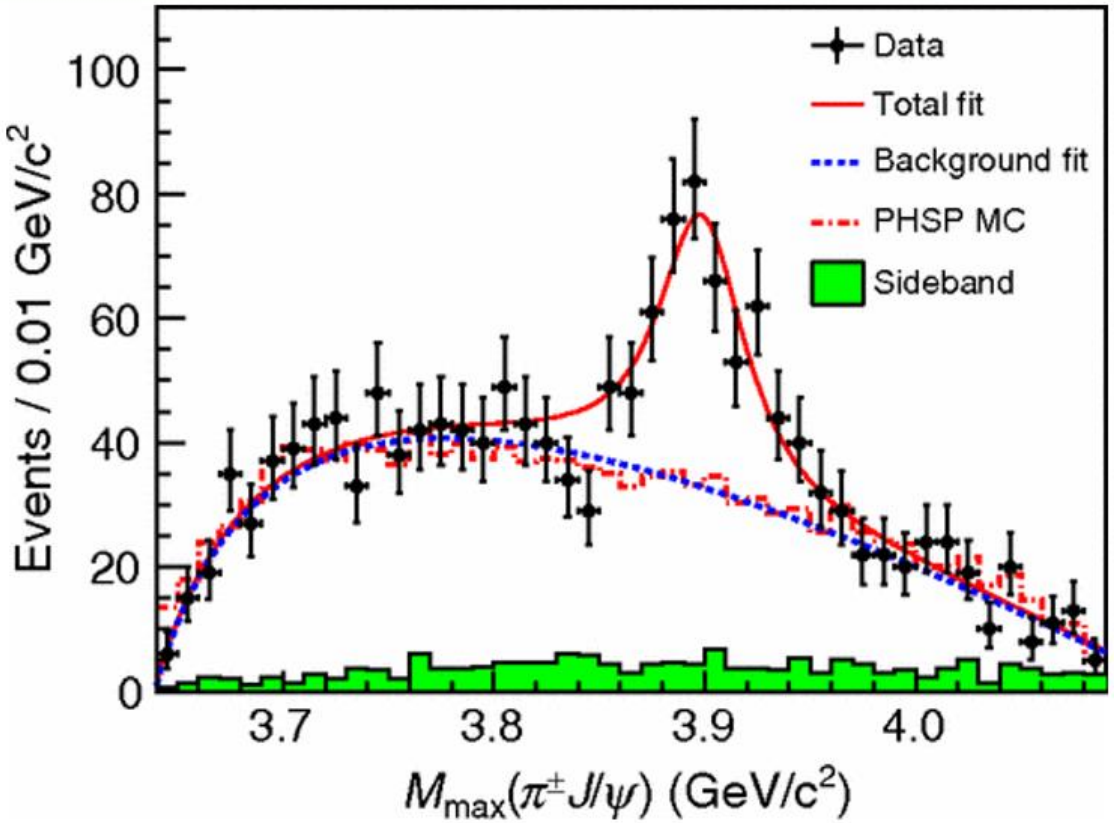
arXiv: 1903.02359

$$\frac{\sigma\left(e^+e^- \to \pi^\mp Z_c(3900)^\pm \to \pi^+\pi^- J/\psi\right)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (21.3 \pm 3.3 \pm 7.5)\%$$

$$\frac{B\left[Y(4260) \to \pi^\mp Z_c(3900)^\pm\right]}{B[Y(4260) \to \pi^+\pi^- J/\psi]} = 2.4$$

assuming $B[Z_c(3900)^\pm \to \pi^\pm J/\psi] = 9\%$

Discovery of the $Z_c(3900)$ in $\pi^+\pi^- J/\psi$
PRL 110, 252001 (2013)



Combined wit previous results

$$\frac{B[Y(4260) \to \gamma X(3872)]}{B[Y(4260) \to \pi^+\pi^- J/\psi]} = 0.1$$

assuming $B[X(3872) \to \pi^+\pi^- J/\psi] = 5\%$

$$\frac{B[Y(4260) \to \gamma X(3872)]}{B[Y(4260) \to \pi^\mp Z_c(3900)^\pm]} \approx 0.04$$

Possible help from theorist side

- Predictions of the cross sections of production/decay
  - Suggestions of the search/measurement direction
- Selection of the physics solution
  - Interference cause multiple solutions
- Parameterization of resonance/process
  - BW is suitable when the width is large? Near threshold?
  - Good formula for amplitude analysis. Description of light hadrons/effects such as final state interaction (FSI), form factor, cusp effect, threshold enhancement, etc.
- ……

Summary

- After Belle and BaBar via ISR, interesting vector structures have been observed in the electron-position annihilation at BESIII
- BESIII has made a systematic study of these states, many analyses are on-going, with more data in this region more exciting experimental results are expected
- Cooperation between experimentalists and theorists to understand the nature of these exotic states


Thanks!

Other search XYZ in light hadrons

M. Ablikim et al. (BESIII Collaboration), Search for $Z_c(3900)^{\pm} \to \omega\pi^{\pm}$[J]. Phys. Rev. D, 2015, 92(3): 032009.

M. Ablikim et al. (BESIII Collaboration), Measurements of cross section of $e^+e^- \to p\bar{p}\pi^0$ at center-of-mass energies between 4.008 and 4.600 GeV[J]. Phys. Lett. B, 2017, 771: 45-51.

M. Ablikim et al. (BESIII Collaboration), Measurement of cross sections of the interactions $e^+e^- \to \phi\phi\omega$ and $e^+e^- \to \phi\phi\phi$ at center-of-mass energies from 4.008 to 4.600 GeV[J]. Phys. Lett. B, 2017, 774: 78-86.