New results of the vector charmonium-like states at BESIII

Jielei Zhang(zhangjielei@ihep.ac.cn)
(On behalf of BESIII Collaboration)
Xinyang Normal University
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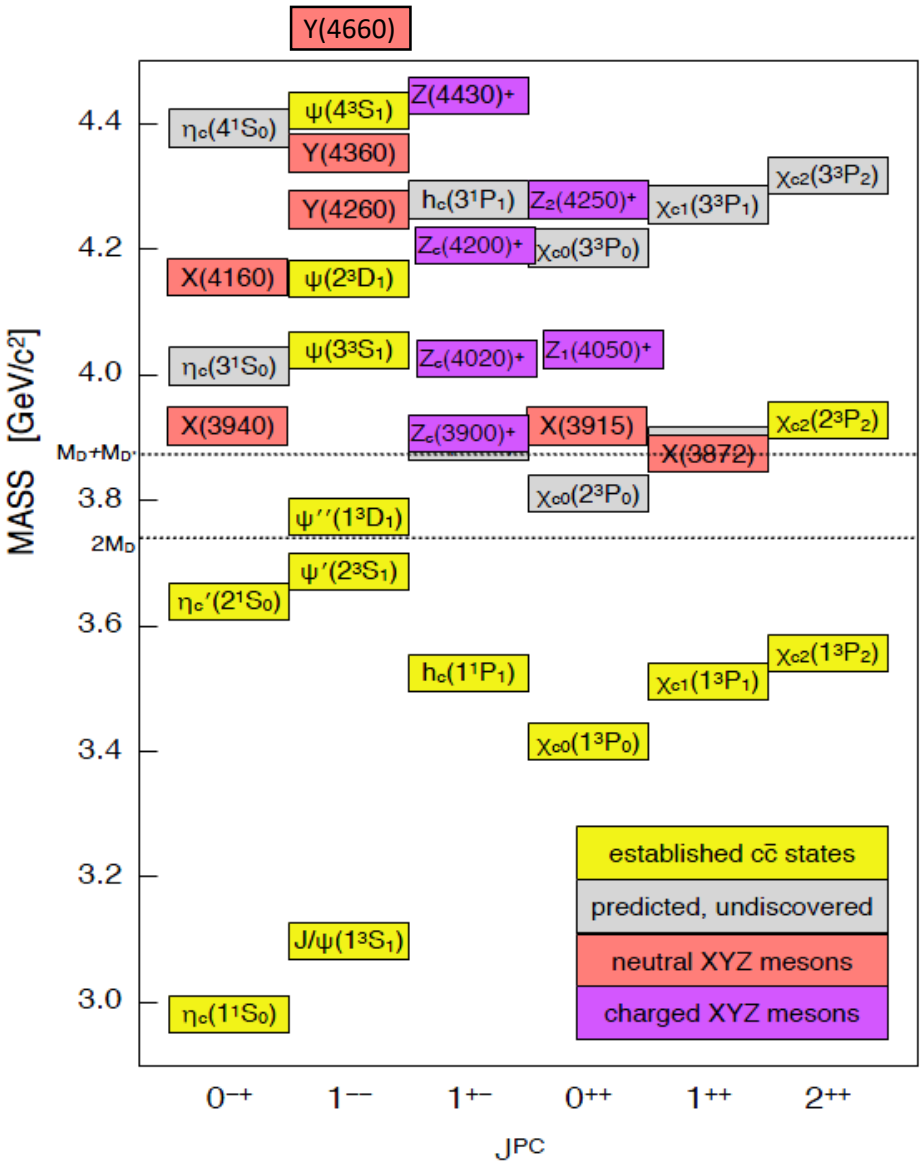
Charmonium(-like) spectrum



➢Below open-charm threshold

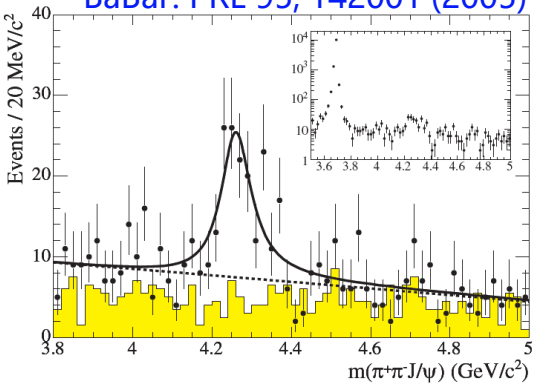
✓Good agreement between experimental measurements and theoretical predictions

➢Above open-charm threshold

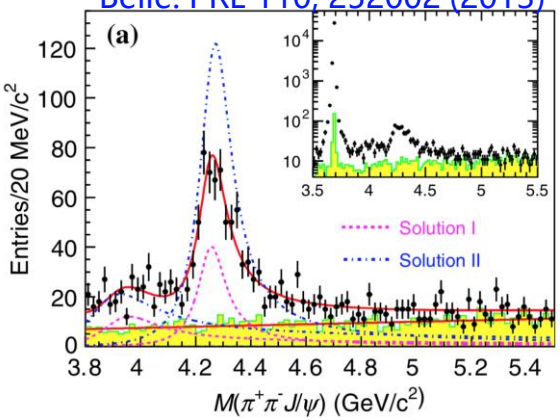
- Many expected states not discovered
- Many unexpected states (charmonium-like or XYZ states) observed:
  - "X" states: Neutral, $J^{PC} \neq 1^{--}$
  - **"Y" states: Neutral, $J^{PC} = 1^{--}$**
  - "Z" states: Charged, isospin triplet

Vector charmonium-like states

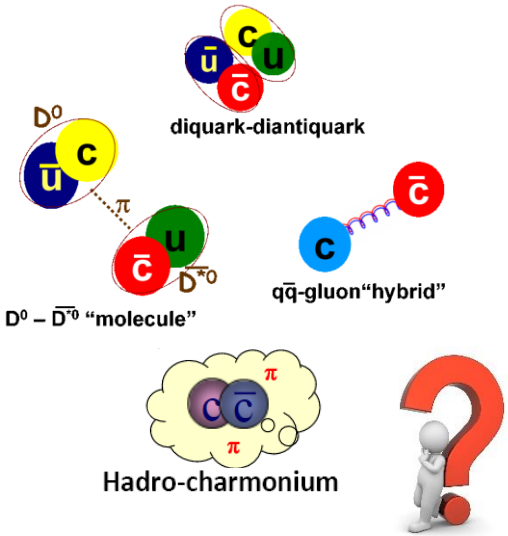
BaBar: PRL 95, 142001 (2005)



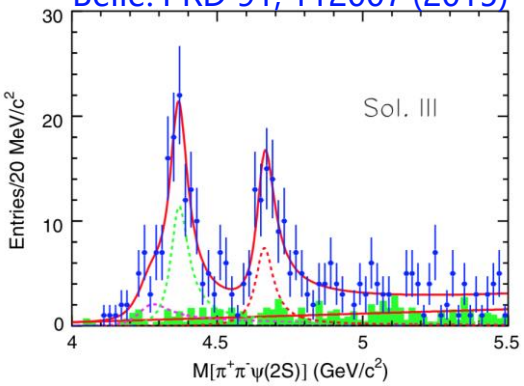
Belle: PRL 110, 252002 (2013)



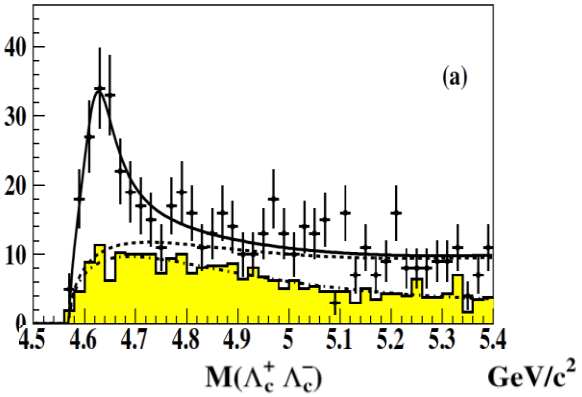
$Y(4260)$
$Y(4360)$
$Y(4660)$



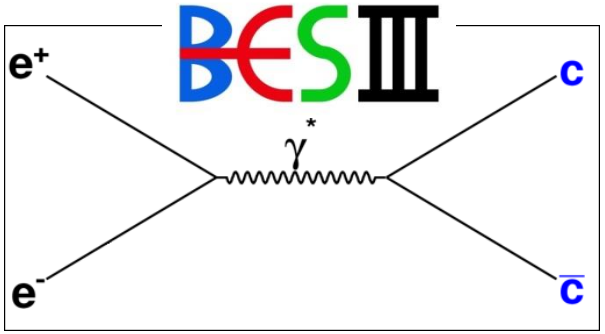
Belle: PRD 91, 112007 (2015)



Belle: PRL 101, 172001 (2008)

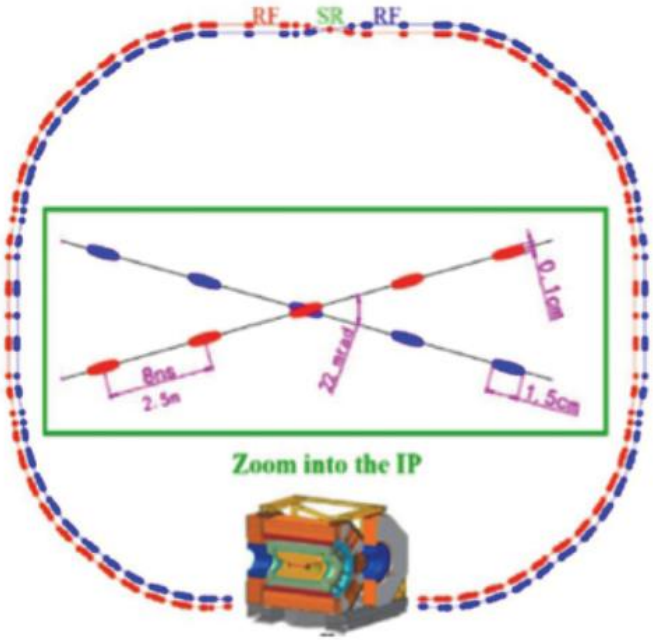


May BESIII help?

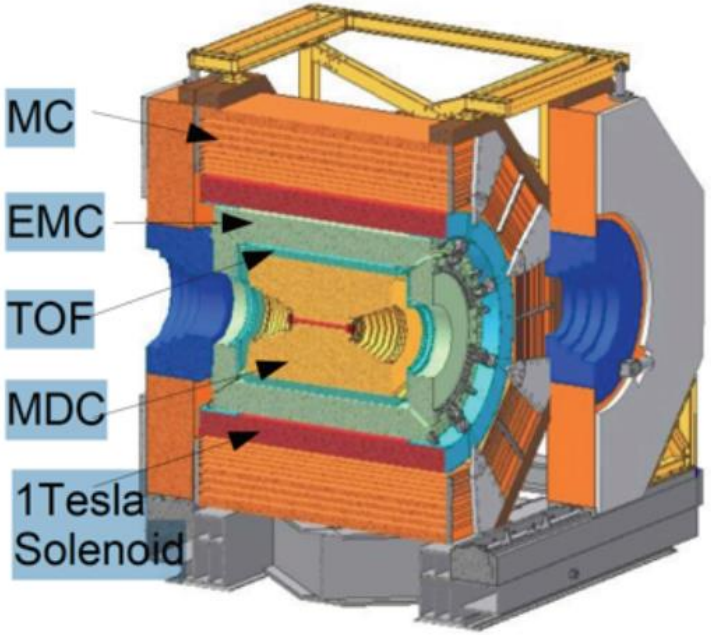


BESIII and BEPCII

Double ring e^+e^- collider:



Multi-purpose detector:

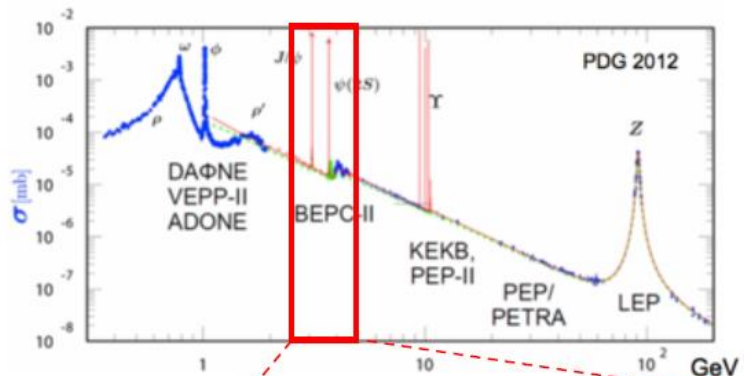


- **Beam energy**: 1.0 – 2.3 GeV
- **Design luminosity**: 10^{33} cm^{-2} s^{-1}
- **Energy spread**: 5.16×10^{-4}
- **Number of bunches**: 93
- **Total current**: 0.91 A
- **Bunch length**: 1.5 cm

Achieved

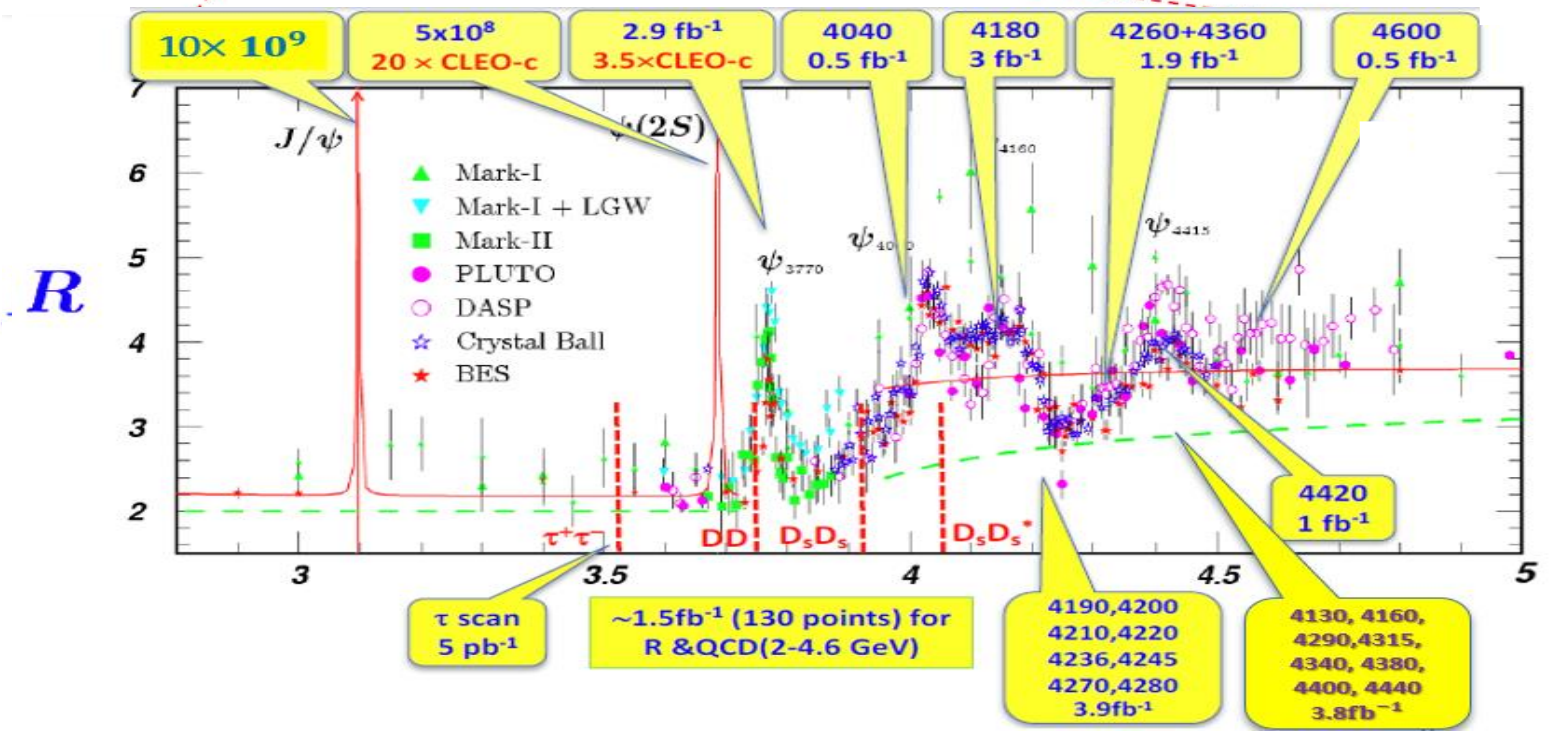
- **Multilayer Drift Chamber**
  $\sigma(p)/p < 0.5\%$ for 1 GeV tracks,
  $\sigma(dE/dx)/dE/dx < 6\%$, $\sigma(xy) = 130\ \mu m$
- **Time of Flight** $\sigma(t) \sim 90$ ps
- **EMCalorimeter** **2.5% @ Barrel**
  5.0% @ Endcaps with 1 GeV
- **Muon Counter** $\sigma(xy) < 2$ cm

BESIII data samples



BESIII has collected the largest data samples of the J/ψ and $\psi(3686)$ in the world, and $> 10\ \mathrm{fb}^{-1}$ above $4.0\ \mathrm{GeV}$ in total.

What can we do with these data?



Recent studies of vector charmonium-like states

Hadronic transition

- $\pi^+\pi^- J/\psi$
- $\pi^+\pi^- h_c$
- $\pi^+\pi^- \psi(3686)$
- $\omega\chi_{c0}$
- $\pi^+\pi^- \psi(3770)$
- $K\bar{K}J/\psi$

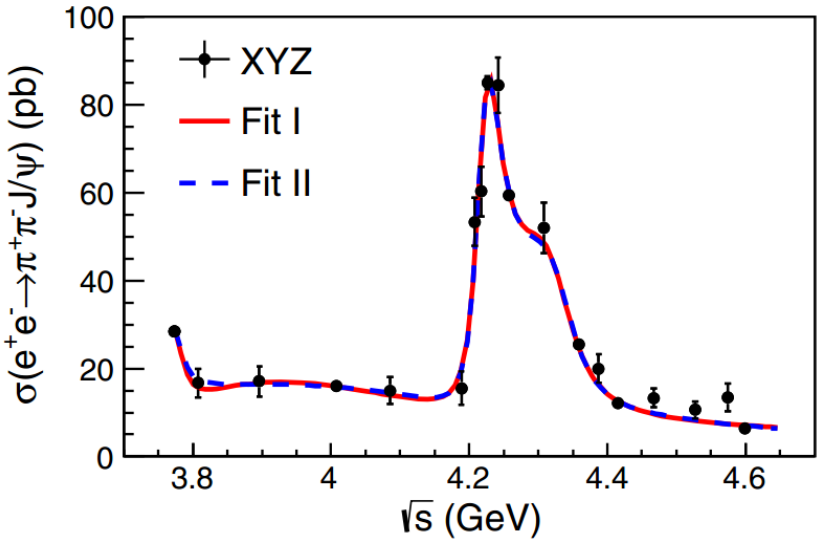
Open charm

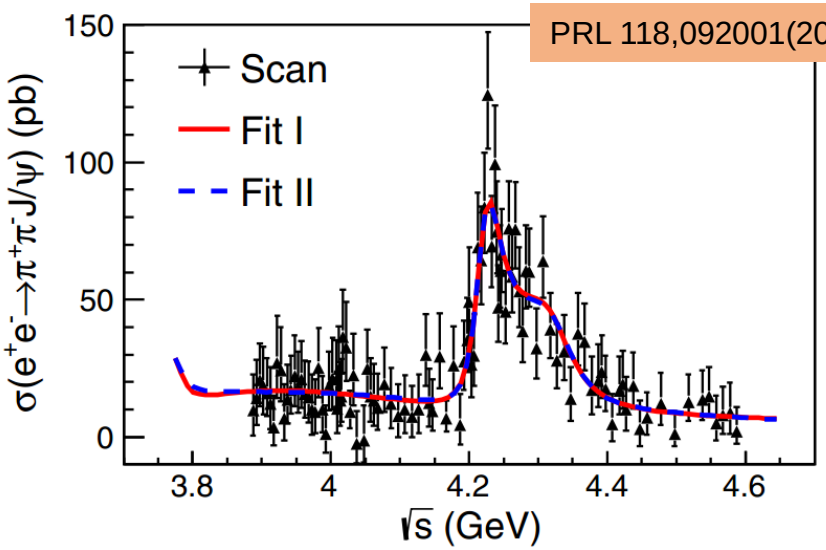
- $\pi^+ D^0 D^{*-}$
- $D_1(2420)^0 \bar{D}^0$
- $\Lambda_c^+ \bar{\Lambda}_c^-$

Light hadron

- $K_S^0 K^\pm \pi^\mp$
- $K_S^0 K^\pm \pi^\mp \pi^0/\eta$

Cross section measurement of $e^+e^- \to \pi^+\pi^- J/\psi$





PRL 118,092001(2017)

Parameters	Fit result
$M(R_1)$	$3812.6^{+61.9}_{-96.6}$ $(\cdots)$
$\Gamma_{\rm tot}(R_1)$	$476.9^{+78.4}_{-64.8}$ $(\cdots)$
$M(R_2)$	4222.0 ± 3.1 (4220.9 ± 2.9)
$\Gamma_{\rm tot}(R_2)$	44.1 ± 4.3 (44.1 ± 3.8)
$M(R_3)$	4320.0 ± 10.4 (4326.8 ± 10.0)
$\Gamma_{\rm tot}(R_3)$	$101.4^{+25.3}_{-19.7}$ $(98.2^{+25.4}_{-19.6})$

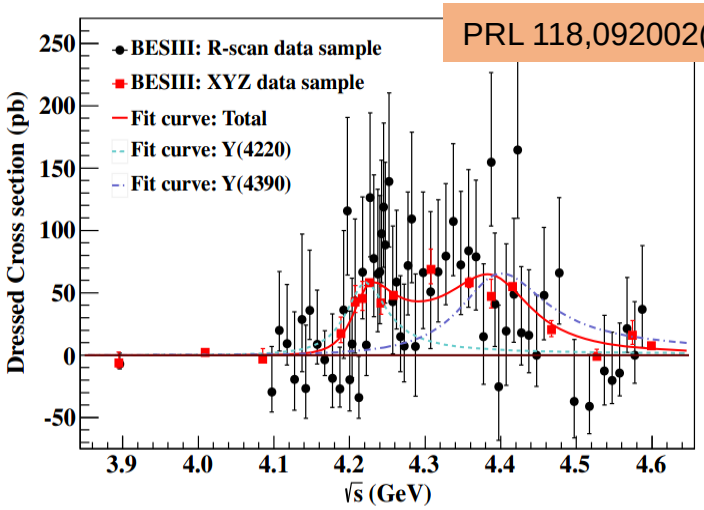
- R_1: not significant, cannot confirm $Y(4008)$
- R_2: $Y(4260)$, much narrower than previous results, $Y(4260) \to Y(4220)$
- R_3: significance larger than 7.6σ, parameters consist with $Y(4360)$

Cross section measurement of $e^+e^- \to \pi^+\pi^- h_c$

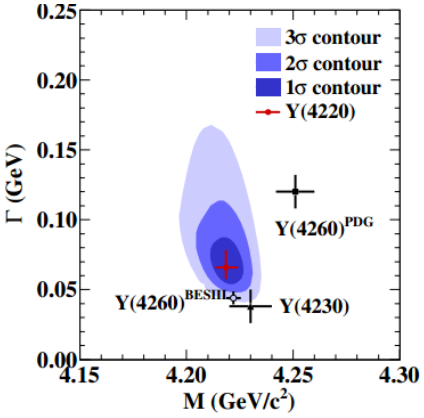
$$\sigma(m) = \left| B_1(m)\sqrt{\frac{P(m)}{P(M_1)}} + e^{i\phi} B_2(m)\sqrt{\frac{P(m)}{P(M_2)}} \right|^2$$

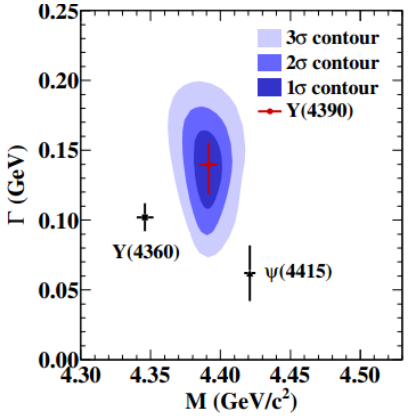
$B_i(m)$: constant width Breit-Wigner function
$P(m)$: 3-body phase space factor
ϕ: relative phase between two resonances

PRL 118,092002(2017)



significance of two structures assumption over one structure $> 10\sigma$





	M (MeV)	Γ_{tot} (MeV)	$\Gamma_{ee} \cdot B$ (eV)	ϕ (rad)
$Y(4220)$	$4218.4^{+5.5}_{-4.5} \pm 0.9$	$66.0^{+12.3}_{-8.3} \pm 0.4$	$4.6^{+2.9}_{-1.4} \pm 0.8$	--
$Y(4390)$	$4391.5^{+6.3}_{-6.8} \pm 1.0$	$139.5^{+16.2}_{-20.6} \pm 0.6$	$11.6^{+5.0}_{-4.4} \pm 1.9$	$3.1^{+0.7}_{-0.9} \pm 0.2$

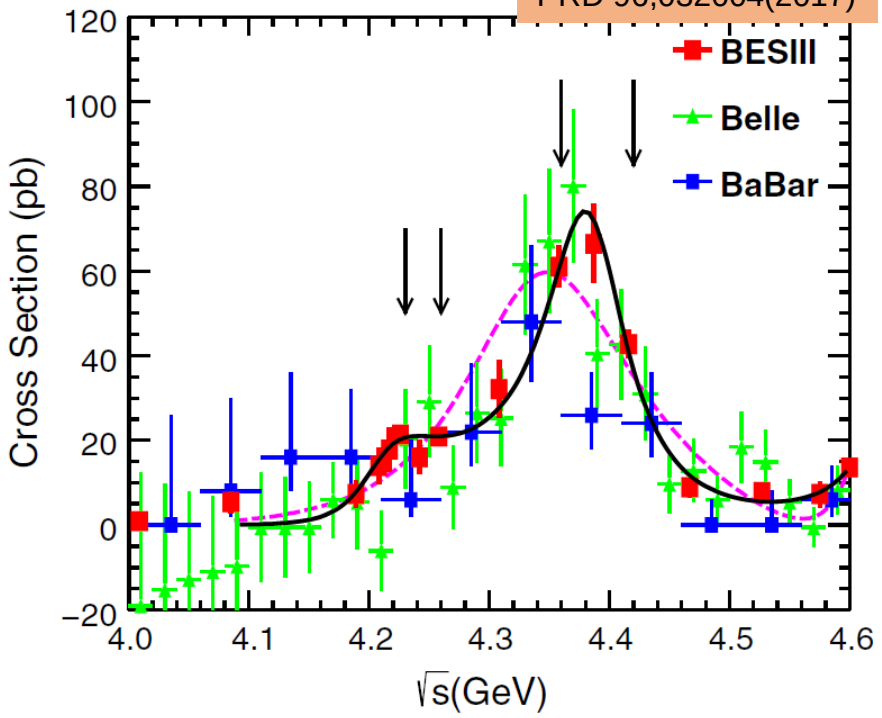
Cross section measurement of $e^+e^- \to \pi^+\pi^-\psi(3686)$

$$\mathcal{A} = f_1 e^{i\phi_1} + f_2 + f_3 e^{i\phi_2}$$

f_1: $Y(4220)$
f_2: $Y(4390)$
f_3: $Y(4660)$

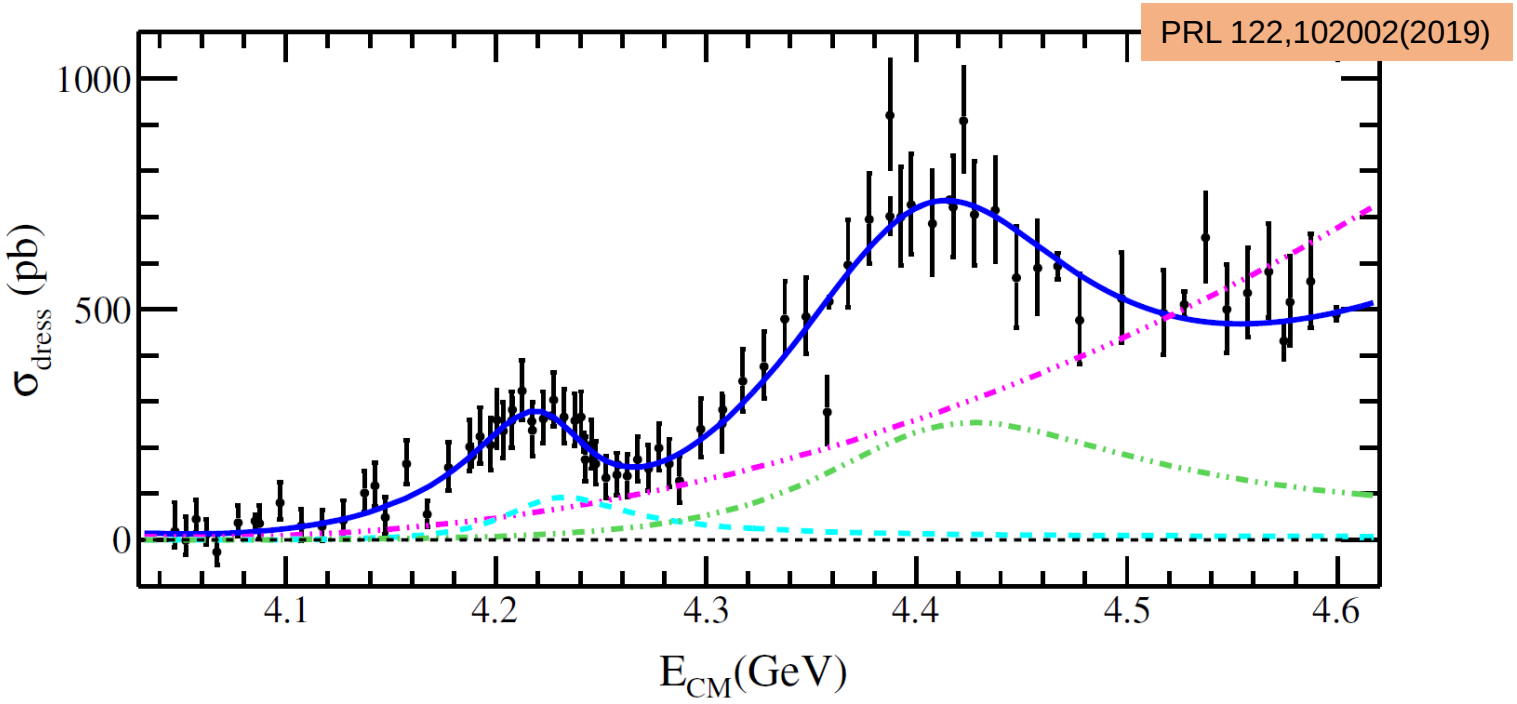
Parameters	Solution I	Solution II
$M(Y4220)$ (MeV/c^2)	4209.5 ± 7.4	
$\Gamma(Y(4220))$ (MeV)	80.1 ± 24.6	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4220))$ (eV)	1.61 ± 1.27	1.80 ± 1.41
$M(Y4390)$ (MeV/c^2)	4383.8 ± 4.2	
$\Gamma(Y(4390))$ (MeV)	84.2 ± 12.5	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4390))$ (eV)	7.25 ± 2.8	10.96 ± 3.8
ϕ_1 (rad)	3.3 ± 1.0	2.8 ± 0.4
ϕ_2 (rad)	0.8 ± 0.9	4.7 ± 0.1

PRD 96,032004(2017)



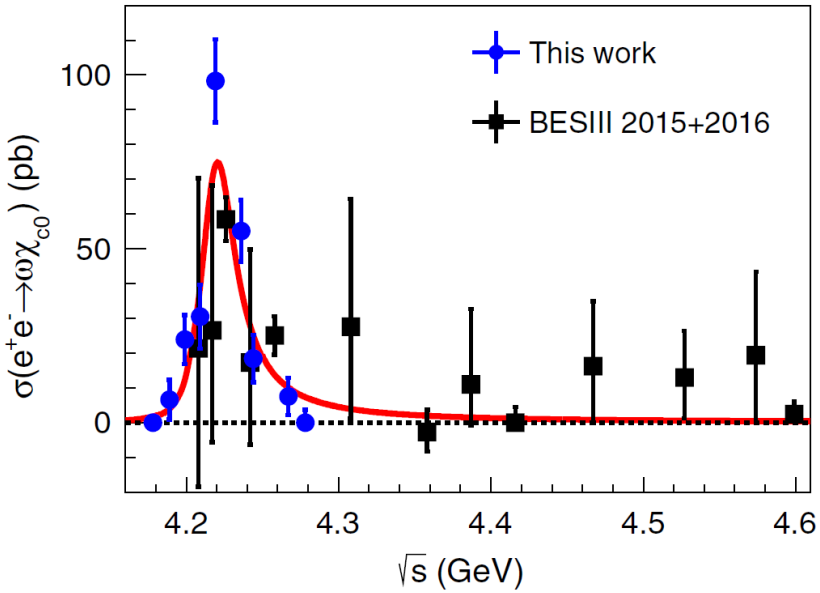
- $Y(4220)$ is necessary, significance=5.8σ
- $Y(4390)$ is consistent with the structure observed in $\pi^+\pi^- h_c$
- Parameters of $Y(4660)$ are fixed to Belle' s results

Cross section measurement of $e^+e^- \to \pi^+ D^0 D^{*-}$

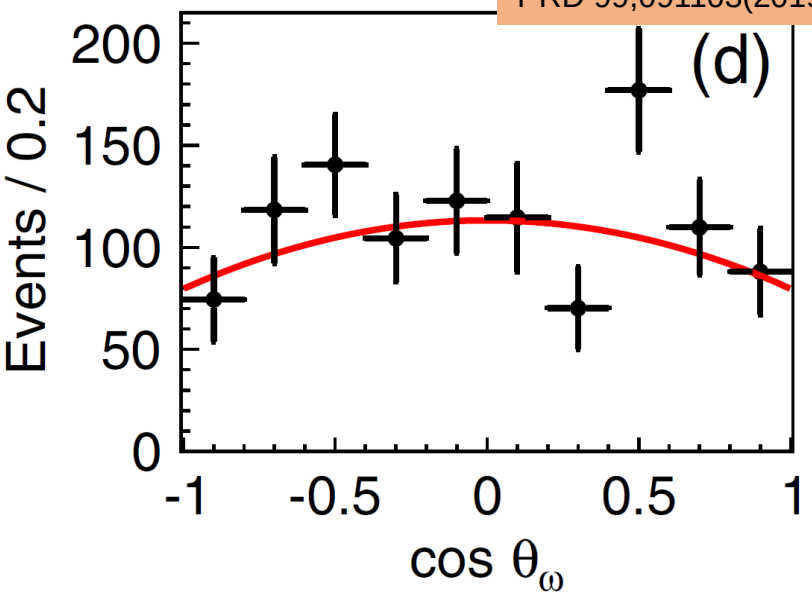


- Fit with a coherent sum of three-body phase space term (pink) and two Breit-Wigner functions (light blue and green)
- $M(Y(4220))$ = (4228.6±4.1±6.3) MeV/c^2, $\Gamma(Y(4220))$ = (77.0±6.8±6.3) MeV

Cross section measurement of $e^+e^- \to \omega\chi_{c0}$

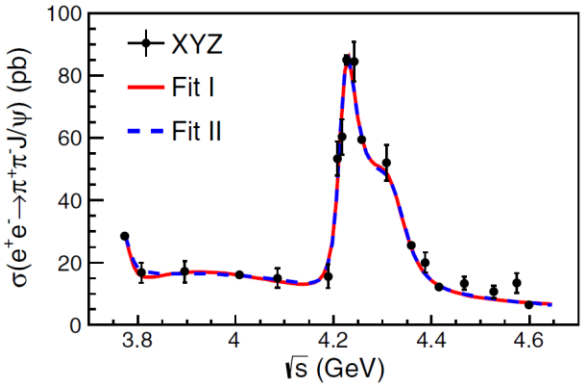


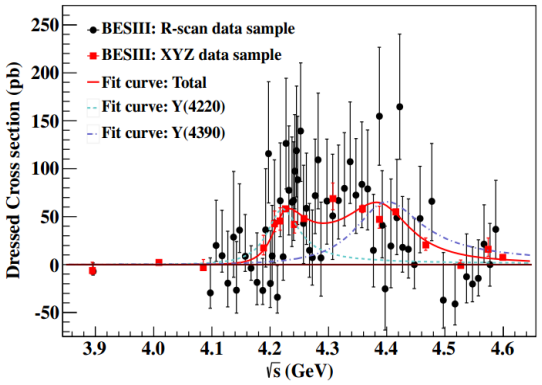
PRD 99,091103(2019)

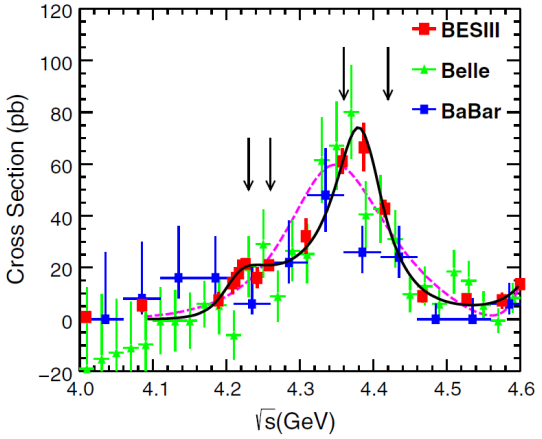


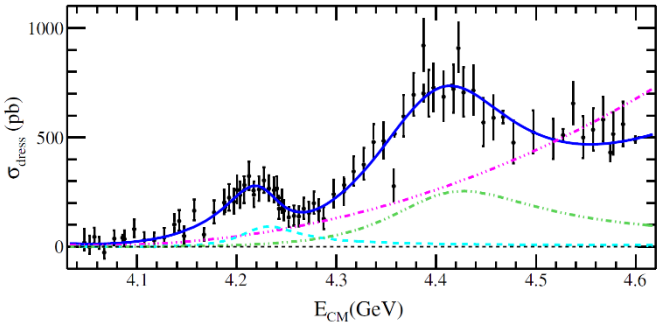
- A structure with $M = (4218.5 \pm 1.6 \pm 4.0)\ \mathrm{MeV}/c^2$, $\Gamma = (28.2 \pm 3.9 \pm 1.6)\ \mathrm{MeV}$
- Angular distribution of the $Y(4220) \to \omega\chi_{c0}$ process is extracted, $\alpha = -0.30 \pm 0.18 \pm 0.05$

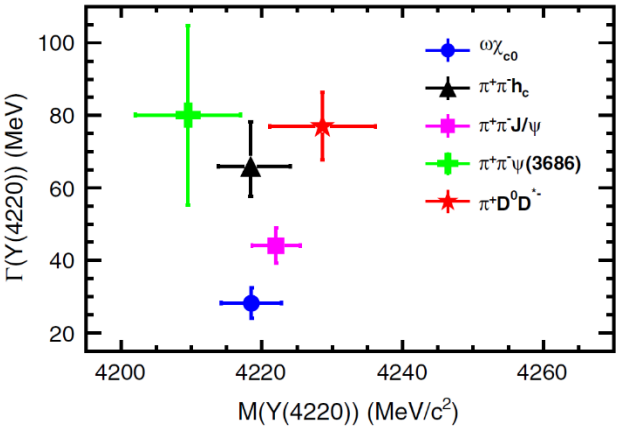
$Y(4260) \rightarrow Y(4220)$

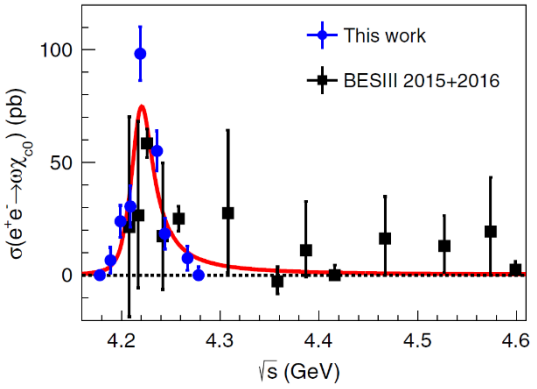








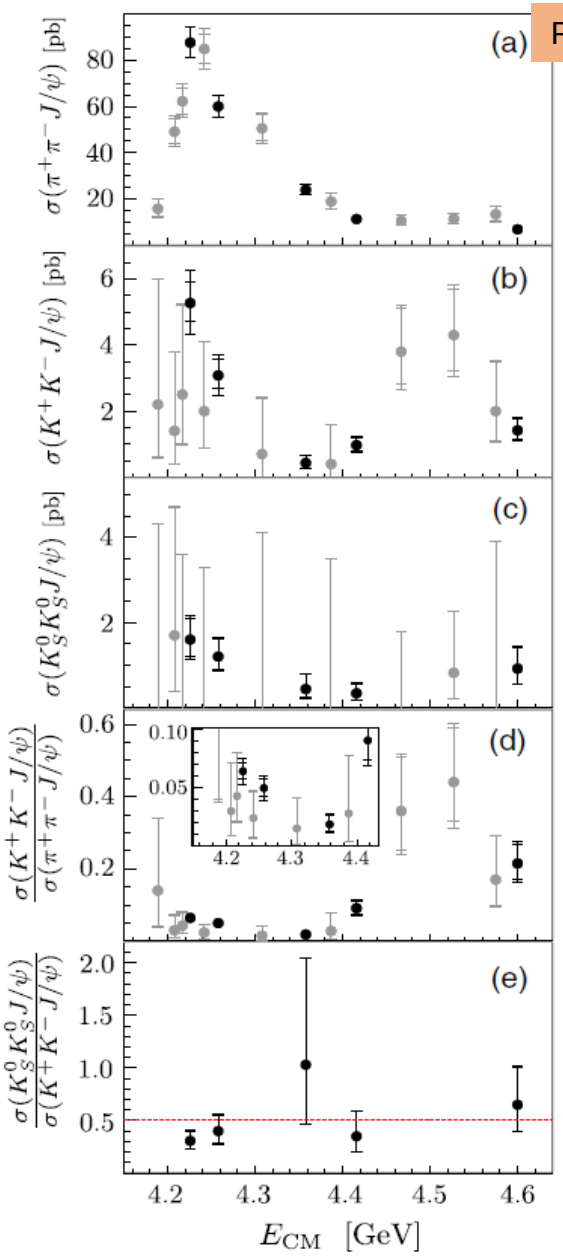




- $Y(4220)$ appears in $\omega\chi_{c0}$, $\pi^+\pi^- h_c$, $\pi^+\pi^- J/\psi$, $\pi^+\pi^-\psi(3686)$ and $\pi^+ D^0 D^{*-}$
- The masses are consistent with each other, mass~4220 MeV

Cross section measurement of $e^+e^- \to K\bar{K}J/\psi$

PRD 97,071101(2018)



$\sigma(\pi^+\pi^- J/\psi)$

$\sigma(K^+K^- J/\psi)$

$\sigma(K_S^0K_S^0 J/\psi)$

$\frac{\sigma(K^+K^- J/\psi)}{\sigma(\pi^+\pi^- J/\psi)}$

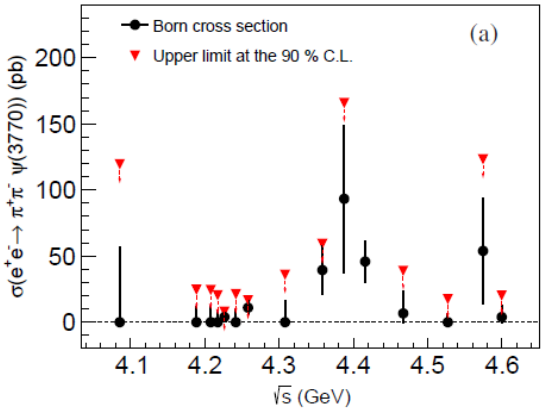
$\frac{\sigma(K_S^0K_S^0 J/\psi)}{\sigma(K^+K^- J/\psi)}$

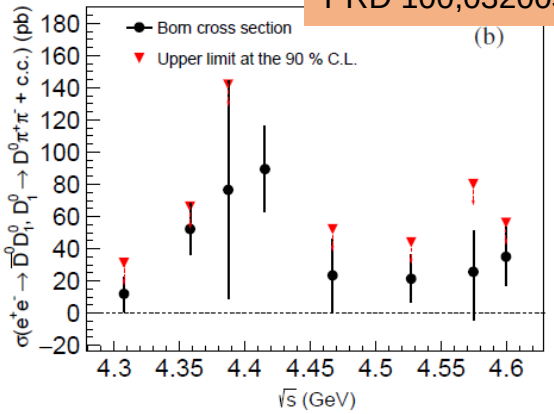
- Cross section for $e^+e^- \to K^+K^- J/\psi$ is different from that for $\pi^+\pi^- J/\psi$ around the $Y(4260)$ region
- There is evidence for a structure around 4.5 GeV in the $e^+e^- \to K^+K^- J/\psi$ cross section that is not present in $\pi^+\pi^- J/\psi$
- The ratio of cross sections for $e^+e^- \to K^+K^- J/\psi$ and $e^+e^- \to K_S^0K_S^0 J/\psi$ is consistent with expectations from isospin conservation

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

PRD 100,032005(2019)

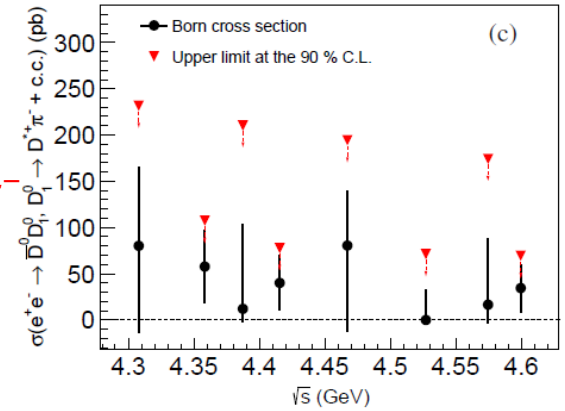
$\pi^+\pi^-\psi(3770)$

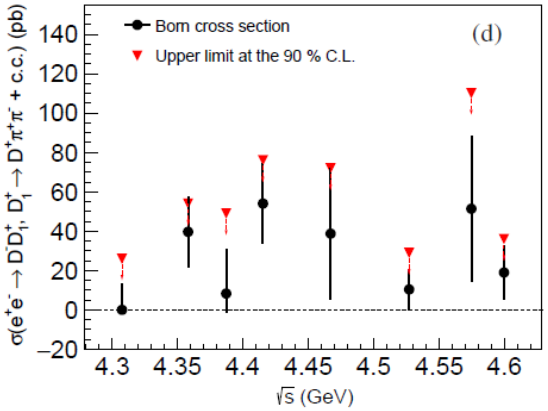




$D_1(2420)^0\bar{D}^0$, $D_1(2420)^0 \to D^0\pi^+\pi^-$

$D_1(2420)^0\bar{D}^0$, $D_1(2420)^0 \to D^{*+}\pi^-$



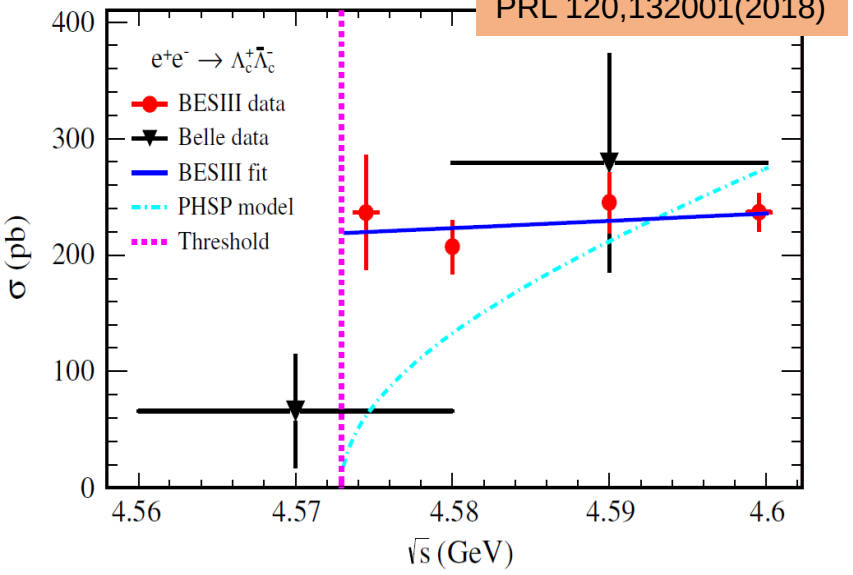


$D_1(2420)^+D^-$, $D_1(2420)^+ \to D^+\pi^+\pi^-$

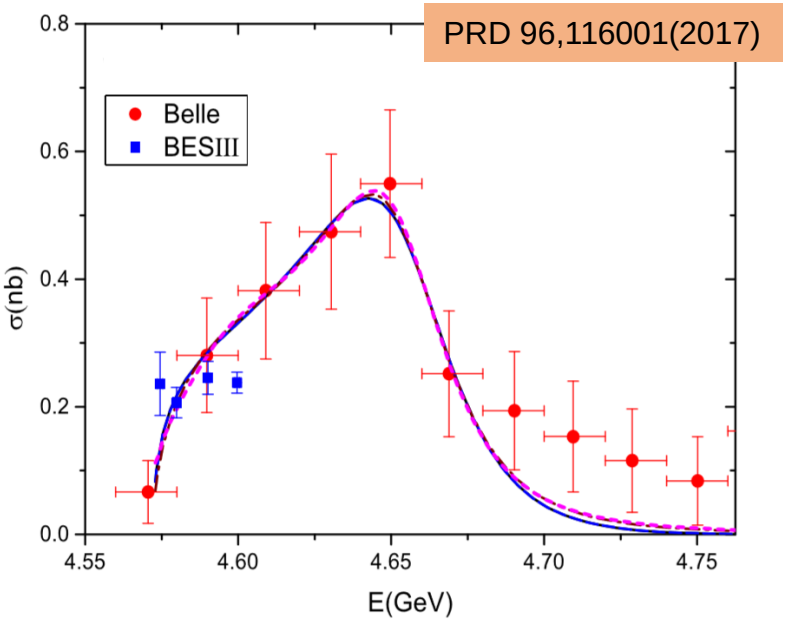
- Process $e^+e^- \to \pi^+\pi^-\psi(3770)$ is observed at $\sqrt{s} = 4.42$ GeV. Whether $\pi^+\pi^-\psi(3770)$ is from the $Y(4390)$ or the $\psi(4415)$ resonance cannot be distinguished.
- Process $e^+e^- \to D_1(2420)^0\bar{D}^0$, $D_1(2420)^0 \to D^0\pi^+\pi^-$ is observed at $\sqrt{s} = 4.42$ GeV.
- No fast rise of the cross section above the $D_1(2420)\bar{D}$ threshold is visible.

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

PRL 120,132001(2018)



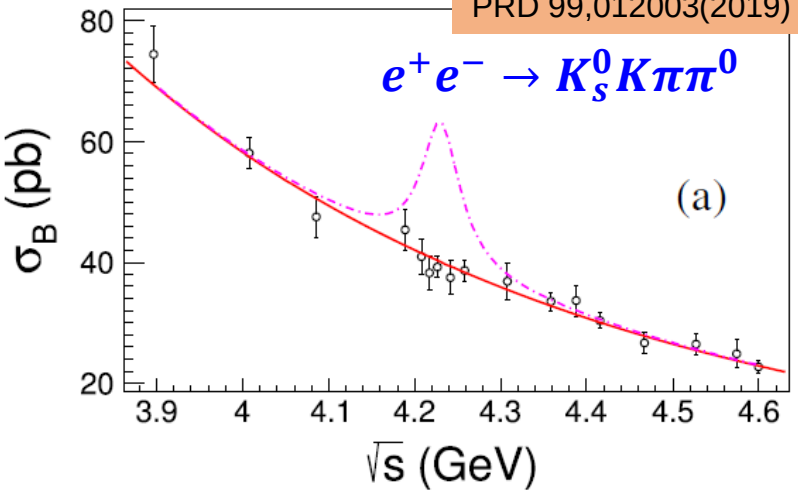
PRD 96,116001(2017)

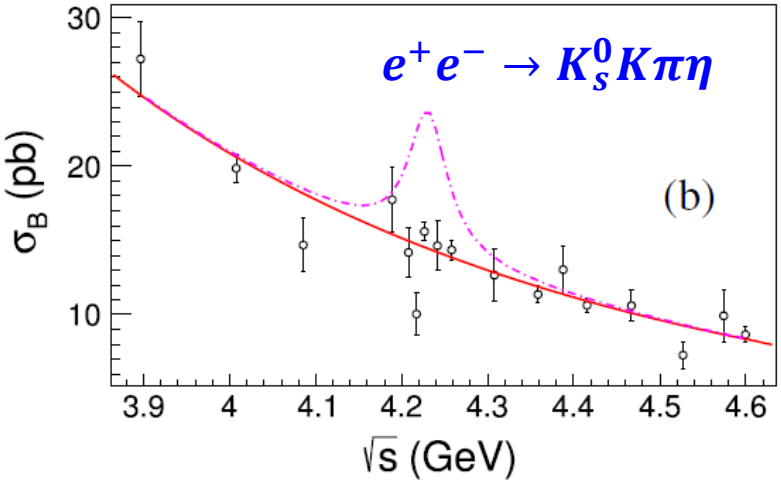


- The enhanced cross section near the $\Lambda_c^+\bar{\Lambda}_c^-$ production threshold is cleared, which indicates the complexity of production behavior of the Λ_c
- More data from BESIII above 4.6 GeV in the future

Cross section measurement of $e^+e^- \to K_S^0 K^\pm \pi^\mp \pi^0/\eta$

PRD 99,012003(2019)

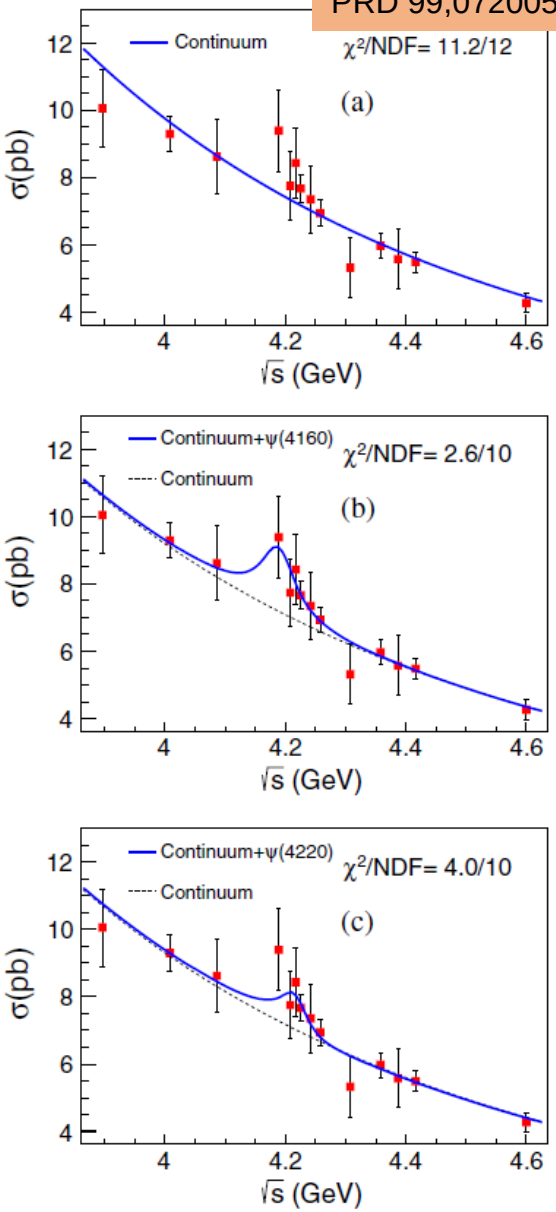




- Searching for $Y(4260)$ decays into light hadrons
- No clear structure is observed in the processes $e^+e^- \to K_S^0 K^\pm \pi^\mp \pi^0/\eta$
- $\Gamma_{e^+e^-}\mathcal{B}\left(Y(4260) \to K_S^0 K^\pm \pi^\mp \pi^0\right) < 0.05$ eV and $\Gamma_{e^+e^-}\mathcal{B}\left(Y(4260) \to K_S^0 K^\pm \pi^\mp \eta\right) < 0.19$ eV at 90% C.L.

Cross section measurement of $e^+e^- \to K_S^0 K^\pm \pi^\mp$

PRD 99,072005(2019)



- BESIII's results agree with BABAR's results, but with significantly improved precision.
- Line shape of the Born cross section is consistent with only the continuum process, however a better fit is obtained by adding an additional resonance $\psi(4160)$ or $Y(4220)$.
- The corresponding significances are only 2.5σ and 2.2σ for $\psi(4160)$ and $Y(4220)$.

Summary

- BESIII has been an excellent laboratory to study charmonium(-like) spectroscopy:
  - High statistics
  - Low background
- $Y(4260) \to Y(4220)$, observed in many hidden charm decay modes $\omega\chi_{c0}$, $\pi^+\pi^- h_c$, $\pi^+\pi^- J/\psi$, $\pi^+\pi^-\psi(3686)$, and also in one open charm decay mode $\pi^+ D^0 D^{*-}$, while no significant signals in light hadron final states.
- Many interesting results have been obtained, only some of them are covered in this talk, and many analyses are ongoing.
- Future:
  - BESIII will take data above 4.6 GeV, it is good opportunity to study the nature of $Y(4660)$ using $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$ and $\pi^+\pi^-\psi(3686)$. More new results can be expected.

More results will come out !!!

Thanks for your attention!