XYZ states at BESIII

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On behalf of the BESIII Collaboration

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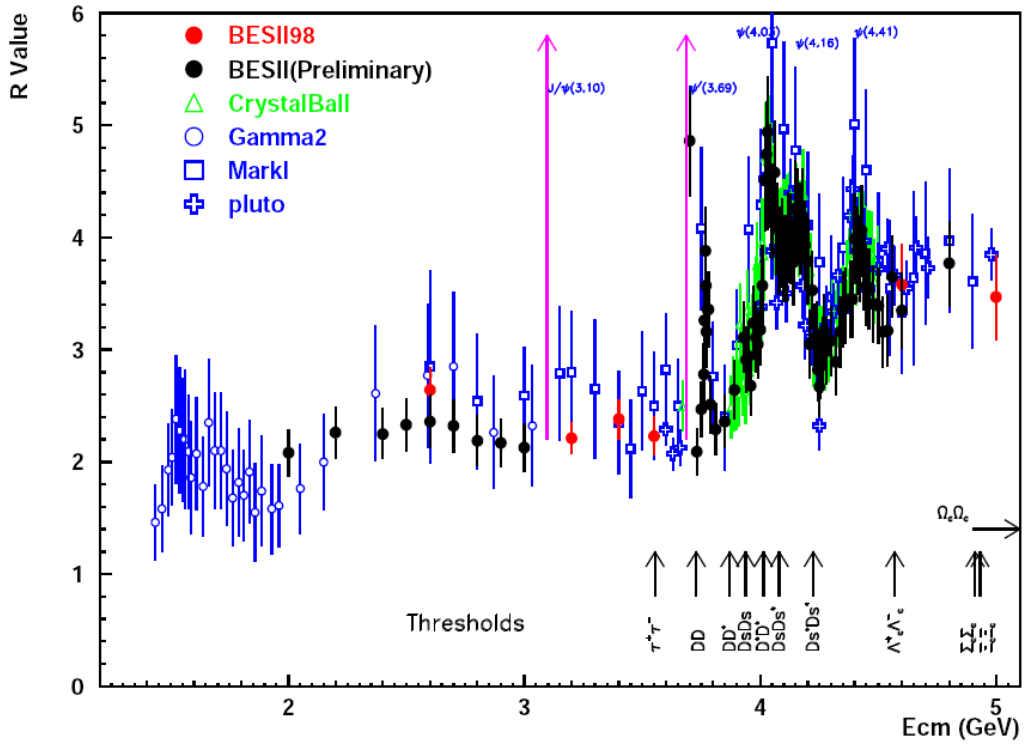
Outline

- The BESIII status
- Charmonimulike states
  - The Y states ($J^{PC}=1^{--}$)
  - The Z_c states (I=1&decays into $c\bar{c}$)
  - The X(3872)&X(3915) ($J^{PC}=1^{++}$)
- Summary

BESIII data Samples

2009: 106M ψ(2S)
225M J/ψ
2010: 975 pb^{-1} at ψ(3770)
2011: 2.9 fb^{-1} at **ψ(3770)** *(total)*
482 pb^{-1} at **4.01 GeV**
2012: 0.45B **ψ(2S)** *(total)*
1.3B **J/ψ** *(total)* now → **10B J/ψ**
2013: 1092 pb^{-1} at **4.23 GeV**
826 pb^{-1} at **4.26 GeV**
540 pb^{-1} at **4.36 GeV**
~50 pb^{-1} at **3.81, 3.90, 4.09, 4.19, 4.21, 4.22, 4.245, 4.31, 4.39, 4.42 GeV**
2014: 1029 pb^{-1} at **4.42 GeV**
110 pb^{-1} at **4.47 GeV**
110 pb^{-1} at **4.53 GeV**
48 pb^{-1} at **4.575 GeV**
567 pb^{-1} at **4.6 GeV**
0.8 fb^{-1} **R-scan** from 3.85 to 4.59 GeV (104 points)



2015: **R-scan** from 2-3 GeV + **2.175 GeV** data
2016: ~3fb^{-1} at 4.18 GeV (for **D_s**)
2017. 500/pb each for 7 energy points between 4.19~4.28 GeV
400/pb around chic_c1
200/pb around X(3872)

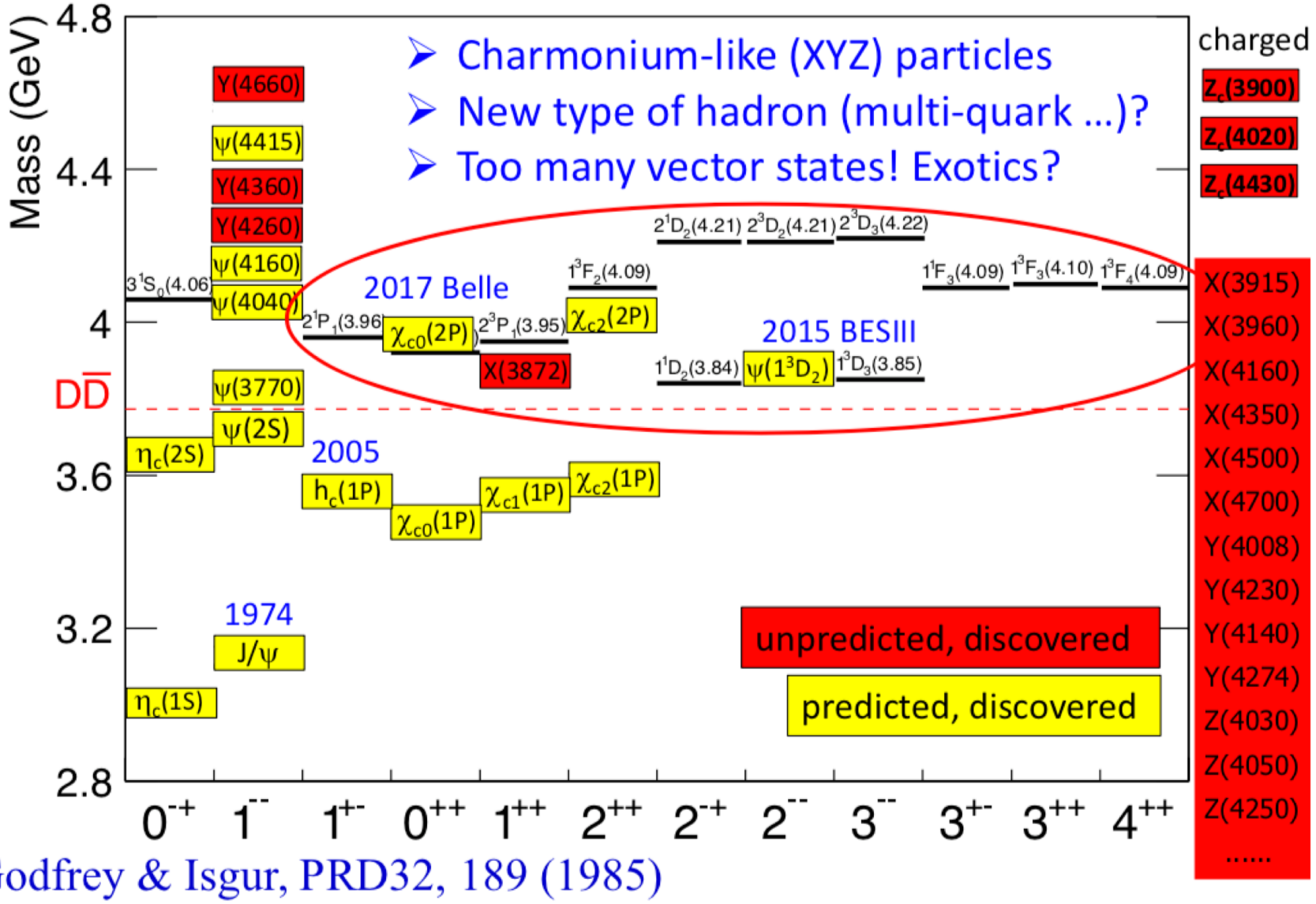
~ 130 points for R scan (~1.3 fb^{-1})

> 10 fb^{-1} above 4.0 GeV in total

2018,2019: J/psi nearby.

2020. More data taking between 4.6-4.7GeV

Charmonium(like) spectroscopy

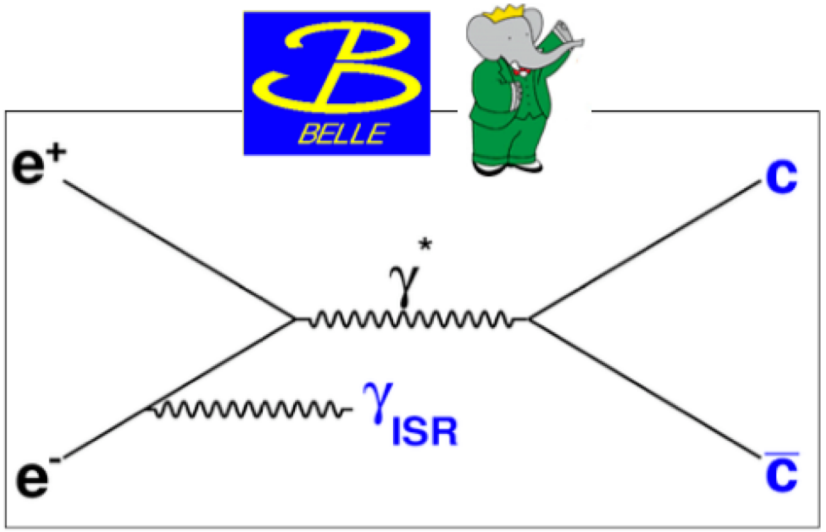


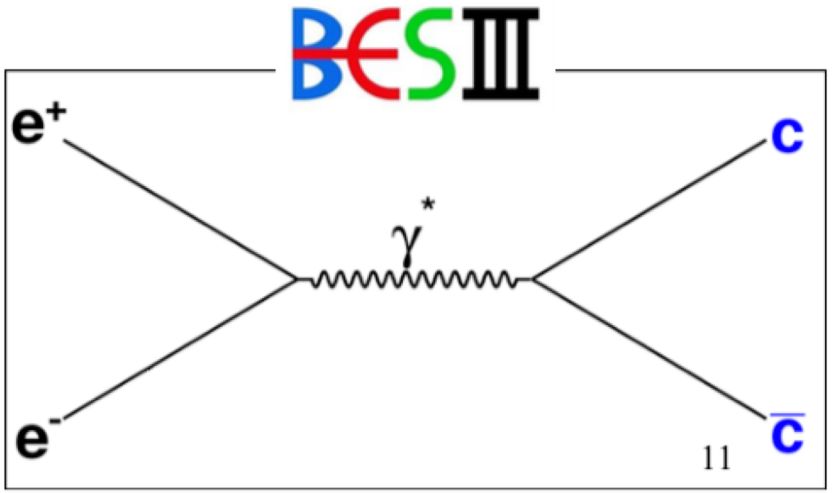
Godfrey & Isgur, PRD32, 189 (1985)

The Y states

measurements of more final states for the

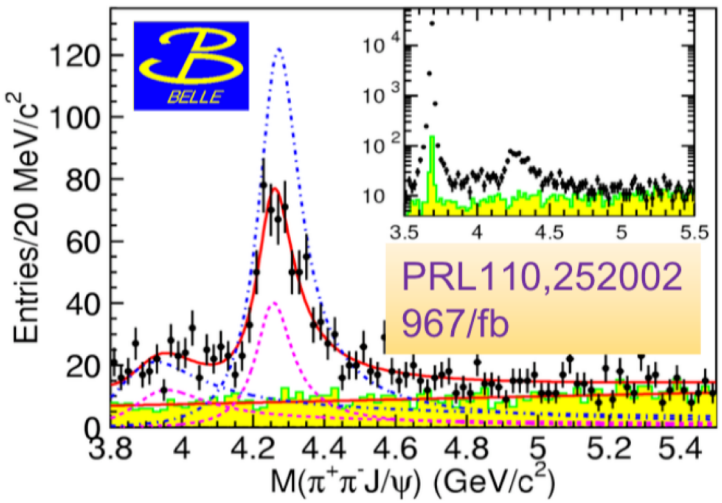
Y and ψ states



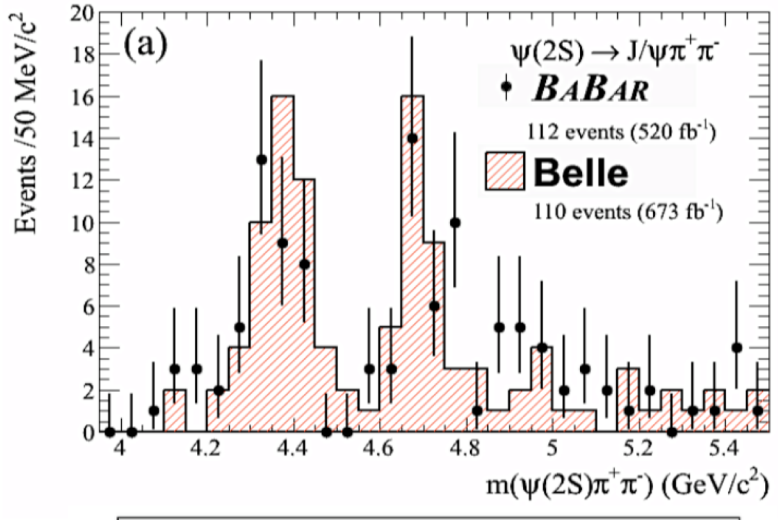


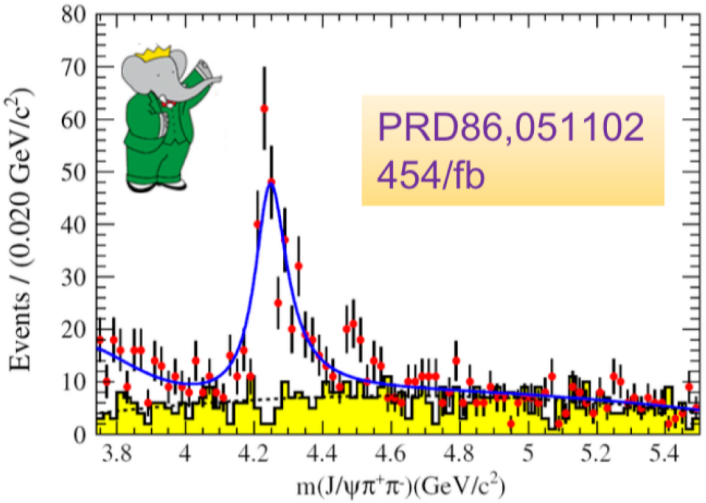
The Y states

Belle: PRL99,142002, 670/fb
BaBar: PRD89, 111103, 520/fb

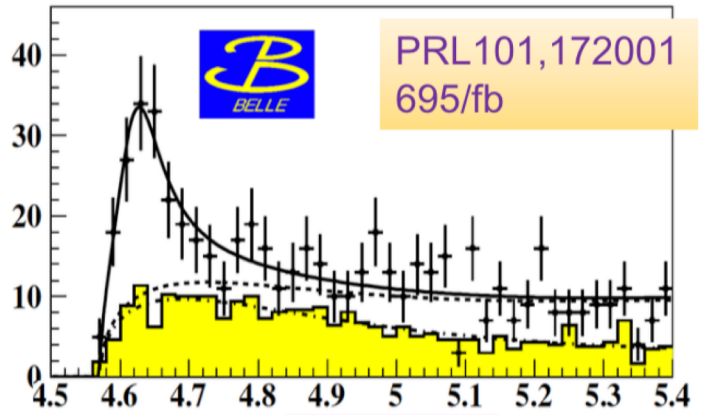


PRL110,252002
967/fb





PRD86,051102
454/fb



PRL101,172001
695/fb

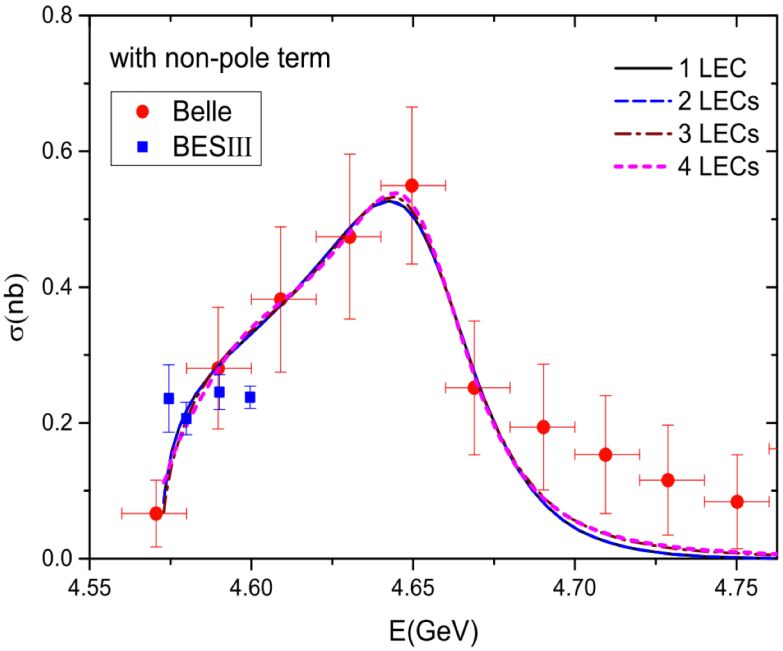
$M(\Lambda_c^+\Lambda_c^-)$

May BESIII help?

Y(4260)/Y(4360) is found in $\pi^+\pi^-J/\psi$ /$\pi^+\pi^-\psi(2S)$.

A peak around 4660 MeV is found both in $\pi^+\pi^-\psi(2S)$ and Λc pair.
The mass and width are consistent with each other .

Y(4660)



Y(4660) baryonic coupling is 10 times larger than mesonic coupling.

[PRD91, 112007 (2014)] [PRL101, 172001 (2008)]

A hidden charm Baryonium?

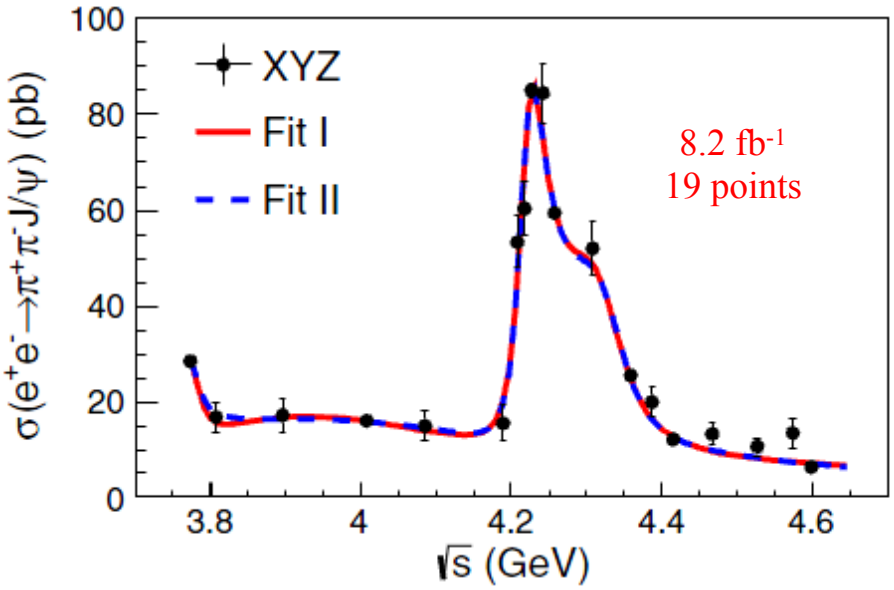
[PRL104, 132005 (2010)]

BESIII indicates different trend for energy dependence comparing with Belle.

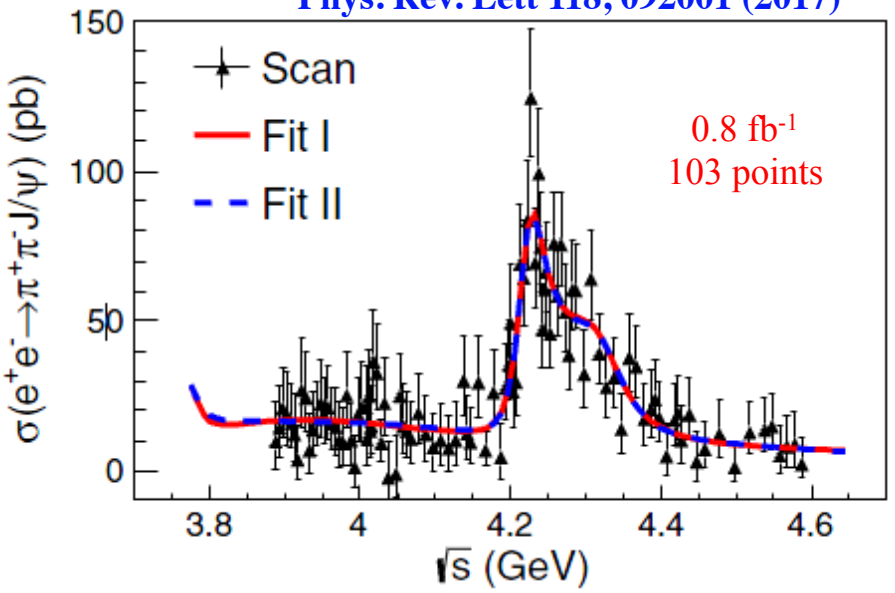
[PRL120, 132001 (2018) [PRD96, 116001 (2017)]

More data from BESIII at threshold and above 4.6 GeV in the future.

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



Phys. Rev. Lett 118, 092001 (2017)

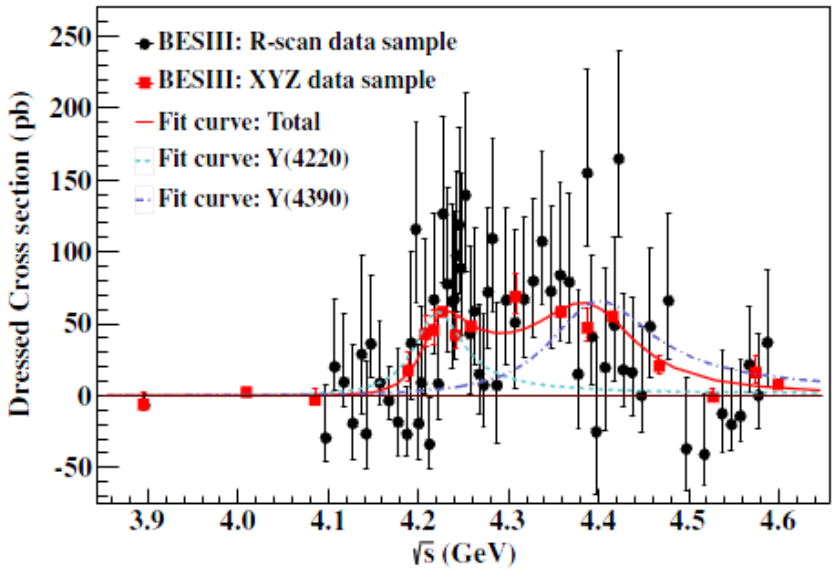


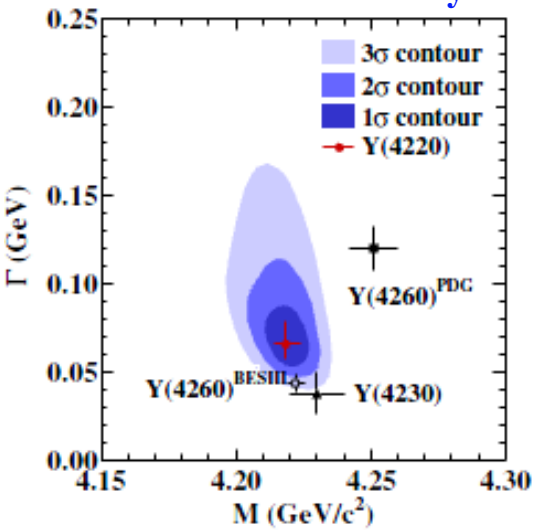
- Most precise cross section measurement for center-of-mass energy from 3.77 to 4.60 GeV;
- Fit I = $|BW_1+BW_2*e^{i\phi 2}+BW_3*e^{i\phi 3}|^2$ or Fit II = $|exp+BW_2*e^{i\phi 2}+BW_3*e^{i\phi 3}|^2$ (other fits ruled out);
- Compare with one Breit-Wigner fit, the significance of the second Breit-Wigner is 7.6σ;
- $Y(4260)+Y(4360)$? The first observation of $Y(4360)\to\pi^+\pi^- J/\psi$.

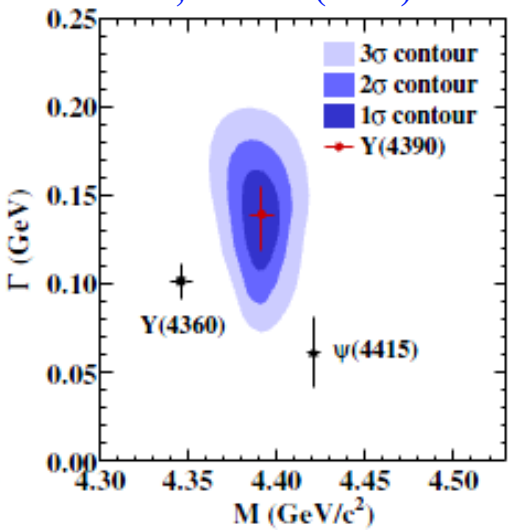
	R_1	R_2	Y(4260) [PDG2016]	Y(4360) [PDG2016]
M (MeV/c^2)	4222.0±3.1±1.4	4320.0±10.4±7.0	4251±9	4346±6
G_{tot} (MeV)	44.1±4.3±2.0	$101.4^{+25.3}_{-19.7}$ ± 10.2	120±12	102±10

$e^+e^- \to \pi^+\pi^- h_c$ cross section

Phys. Rev. Lett 118, 092002 (2017)







- First precise cross section measurement from threshold to 4.6 GeV;
- Fit with $|BW_1+BW_2*e^{i\phi}|^2$, two resonant structures are evident;
- Compare with one Breit-Wigner fit, the significance of the two Breit-Wigner fit is greater than 10σ;
- The parameters of Y(4220) are consistent with those observed in $\pi^+\pi^- J/\psi$ around 4222 MeV.

	M (MeV/c^2)	G_{tot} (MeV)
Y(4220)	$4218.4^{+5.5}_{-4.5} \pm 0.9$	$66.0^{+12.3}_{-8.3} \pm 0.4$
Y(4390)	$4391.5^{+6.3}_{-6.8} \pm 1.0$	$139.5^{+16.2}_{-20.6} \pm 0.6$

Improvement of $e^+e^- \to \pi^+\pi^-\psi'$

PRD 96, 032004 (2017)

- **Data samples:**
  - 16 energy points from $\sqrt{s}$=4.008 to 4.600 GeV.
  - The total integrated luminosity (L_{int}) is 5.1 fb^{-1}.

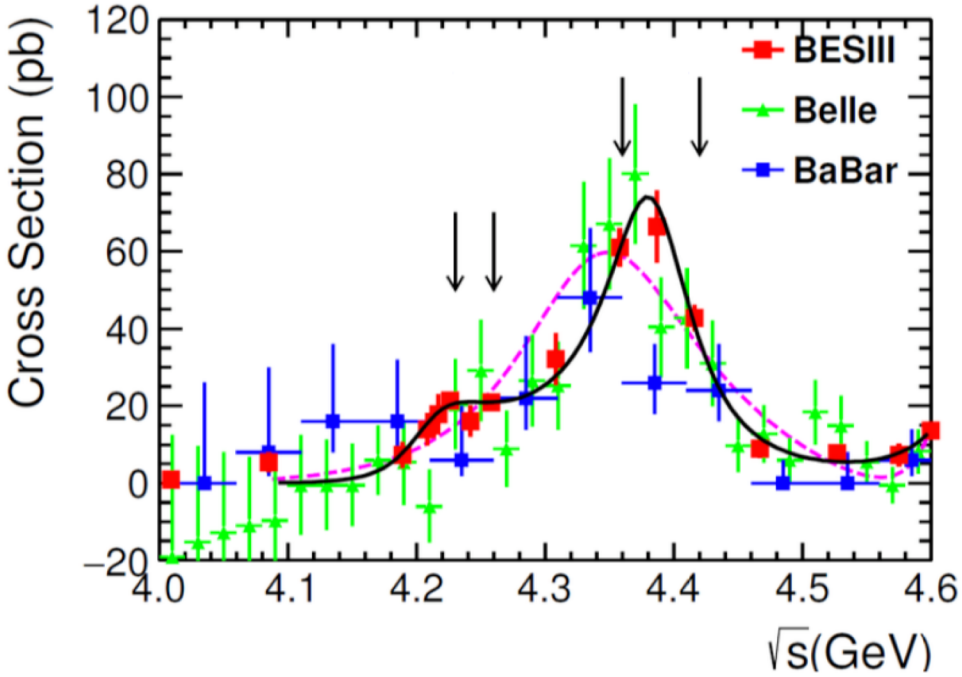
- **Reconstructed modes:**

  Mode I: $\Psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ ($l=e/\mu$)

  Mode II: $\Psi(3686) \to neutrals + J/\psi$,

  $neutrals = (\pi^0\pi^0, \pi^0, \eta \text{ and } \gamma\gamma)$ $J/\psi \to l^+l^-$ ($l=e/\mu$)

The Ys in $e^+e^- \to \pi^+\pi^-\psi'$



Phys. Rev. D 96, 032004 (2017)

The Y(4220) is necessary

(significance = 5.8σ)

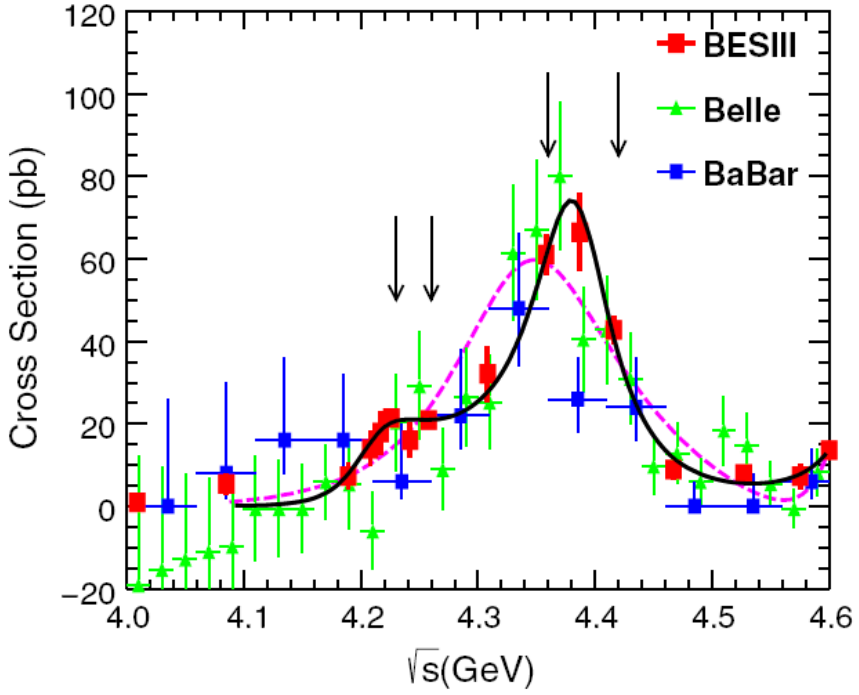
Fix parameters of the Y(4660) to Belle results

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)	0.8 ± 0.7	0.4 ± 0.3
$M(Y4390)$ (MeV/c^2)	4383.8 ± 4.2	
$\Gamma(Y(4390))$ (MeV)	84.2 ± 12.5	
$\mathcal{B}\Gamma^{e^+e^-}(Y(4390))$ (eV)	3.6 ± 1.5	2.7 ± 1.0
ϕ_1 (rad)	3.3 ± 1.0	2.8 ± 0.4
ϕ_2 (rad)	0.8 ± 0.9	4.7 ± 0.1

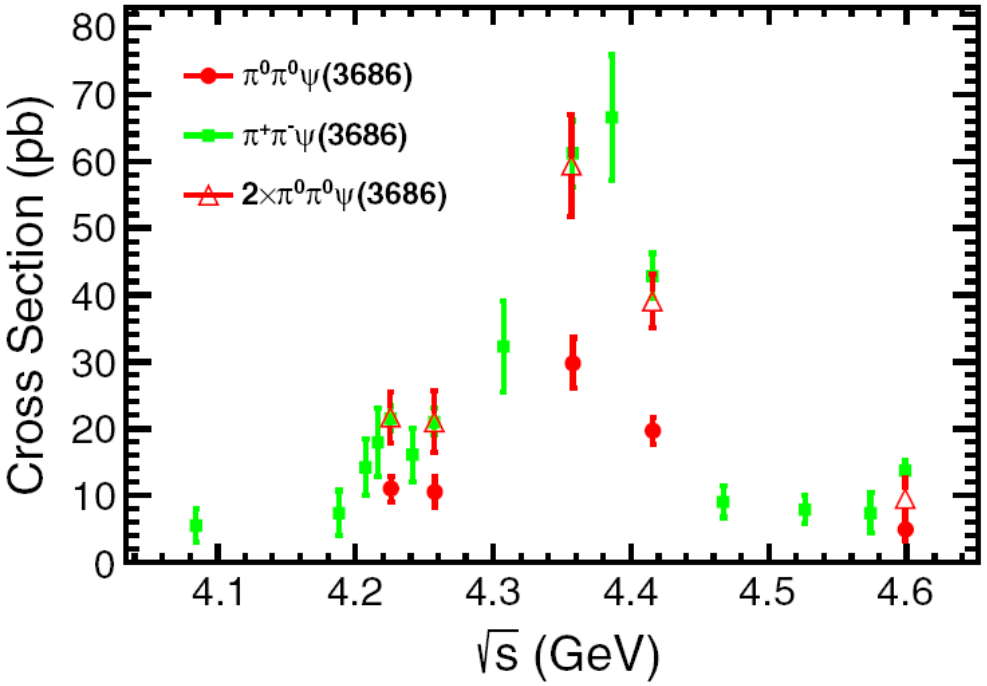
Y(4360)?

$e^+e^- \to \pi^0\pi^0\psi(3686)$

Phys. Rev. D 96, 032004 (2017)



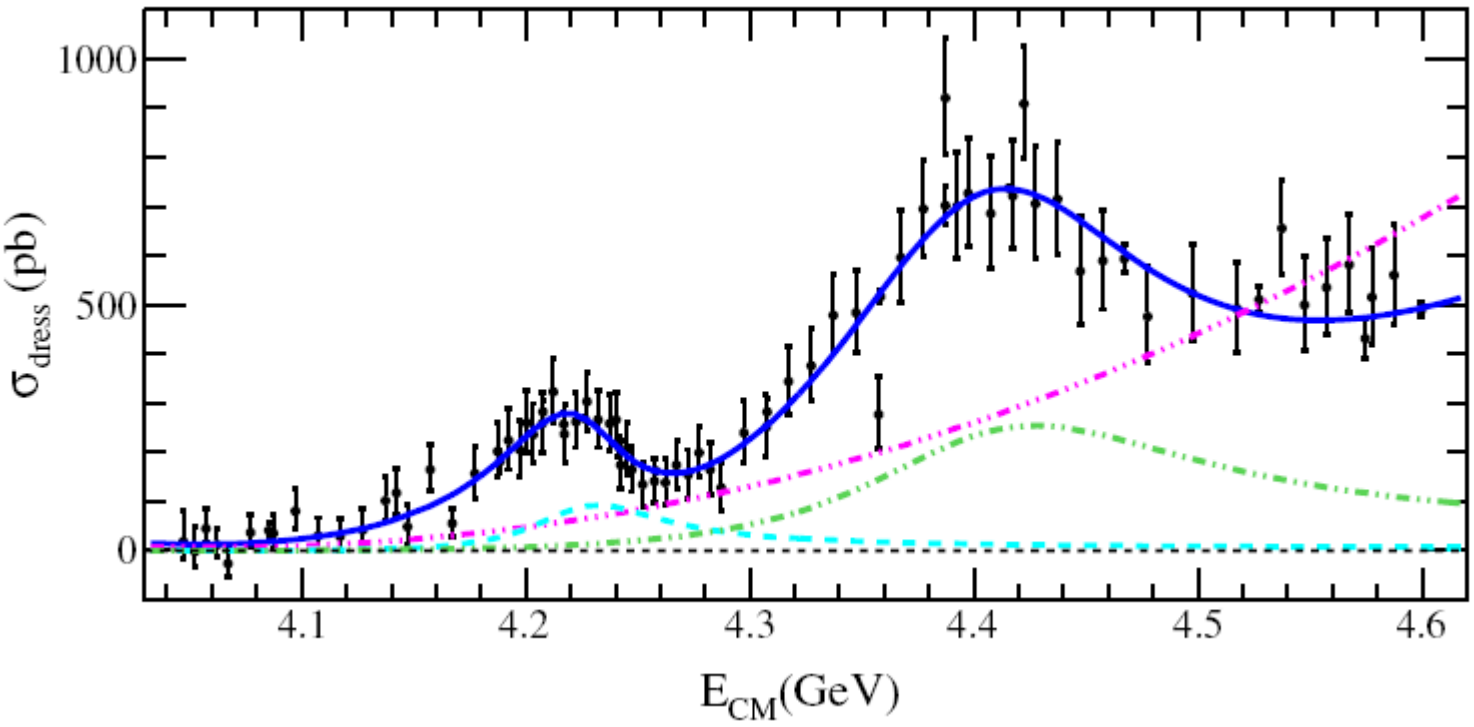
Phys. Rev. D 97, 052001 (2018)



- Y(4360) was observed and subsequently confirmed in $e^+e^- \to (\gamma_{ISR})\pi^+\pi^-\psi(3686)$ by BABAR, Belle, and BESIII, it is interesting to study the Y(4360) in $\pi^0\pi^0$ transition to $\psi(3686)$ and to examine the isospin symmetry;
- Signal process: $e^+e^- \to \pi^0\pi^0\psi(3686)$, $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \ell^+\ell^-(\ell = e\ or\ \mu)$;
- 16 energy points from $\sqrt{s}$ = 4.008 to 4.600 GeV, the total luminosity is about 5.2 fb^{-1};
- The result of cross section measurement is consistent with the charged mode from isospin symmetry.

Phys. Rev. Lett. 122, 102002 (2019)

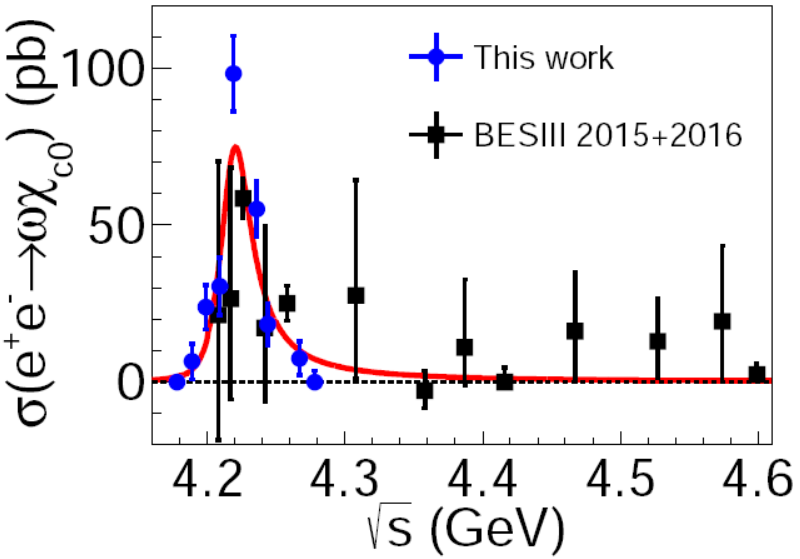
$e^+e^- \to \pi^+ D^0 D^{*-}$

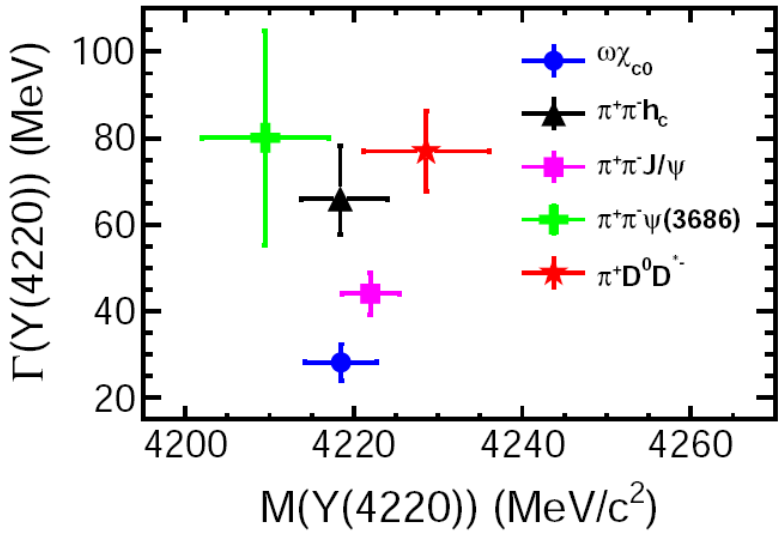


- Most precise cross section measurement for center-of-mass energy from 4.05 to 4.60 GeV;
- Fit with a coherent sum of three-body phase space term (pink dashed triple-dot line) and two Breit-Wigner functions (green dashed double-dot line and aqua dashed line);
- The statistical significance of two resonant assumption over one resonant assumption is greater than 10σ;
- $M(Y(4220))$ = (4228.6±4.1±6.3) MeV/c^2, $\Gamma(Y(4220))$ = (77.0±6.8±6.3) MeV.

Improve measurement $e^+e^- \to \omega\chi_{c0}$

Accepted by Phys. Rev. D (RC); arXiv: 1903.02359v1 [hep-ex]

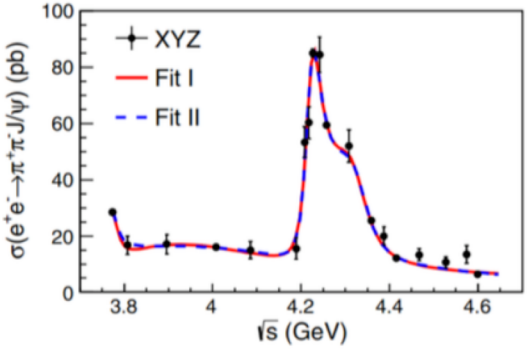


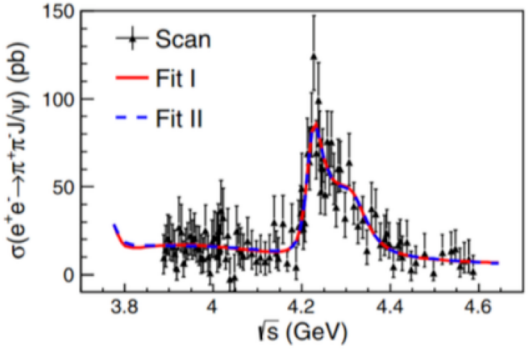


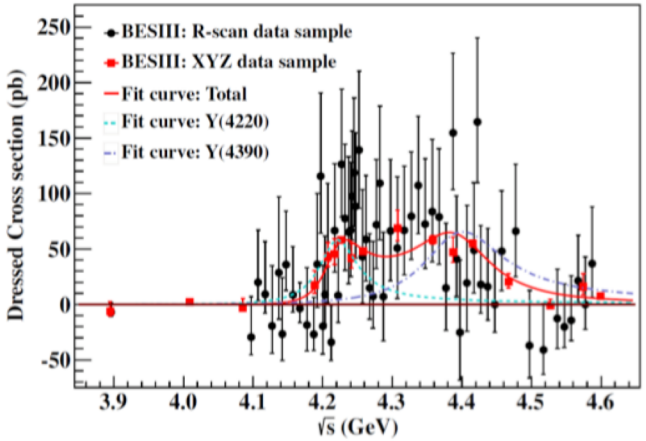
$$M = (4218.5 \pm 1.6 \pm 4.0)\ \text{MeV/c}^2$$
$$\Gamma = (28.2.0 \pm 3.9 \pm 1.6)\ \text{MeV}$$

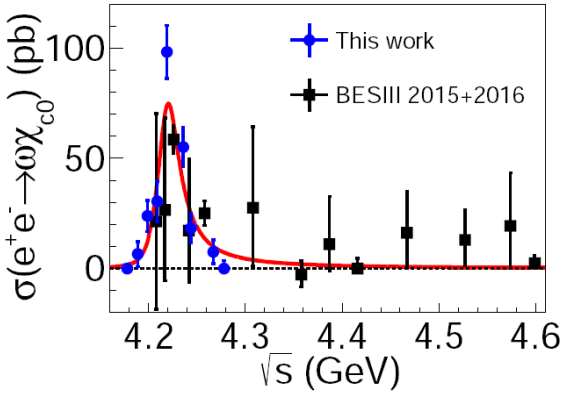
- This observation confirms and improves the previous result;
- Further experimental studies with higher statistics are needed to draw a more reliable conclusion on the nature of this structure.

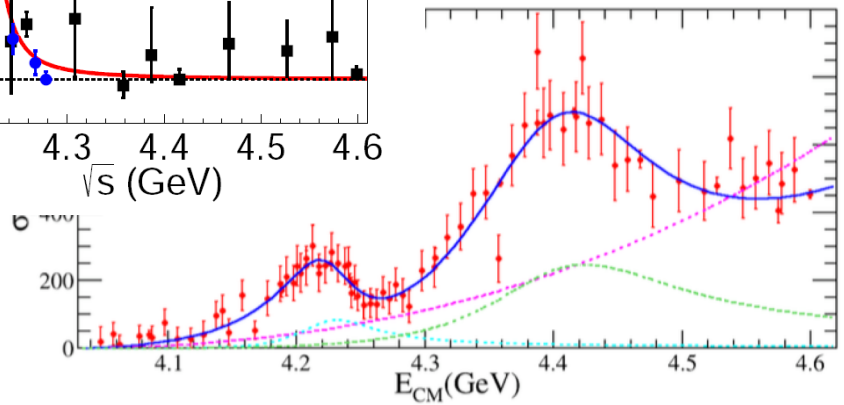
Y(4260)➔Y(4220): what is it?

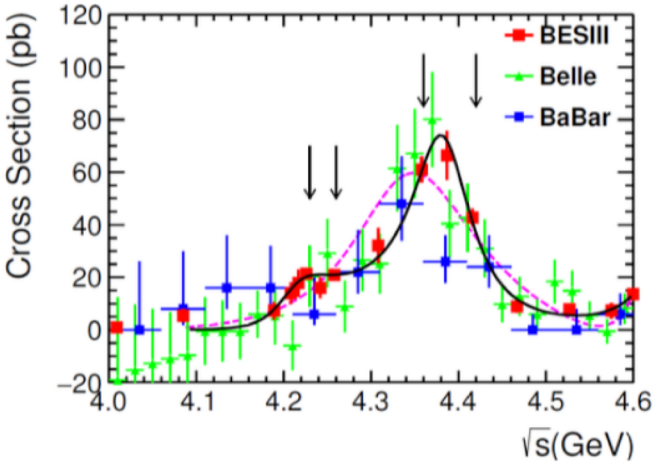








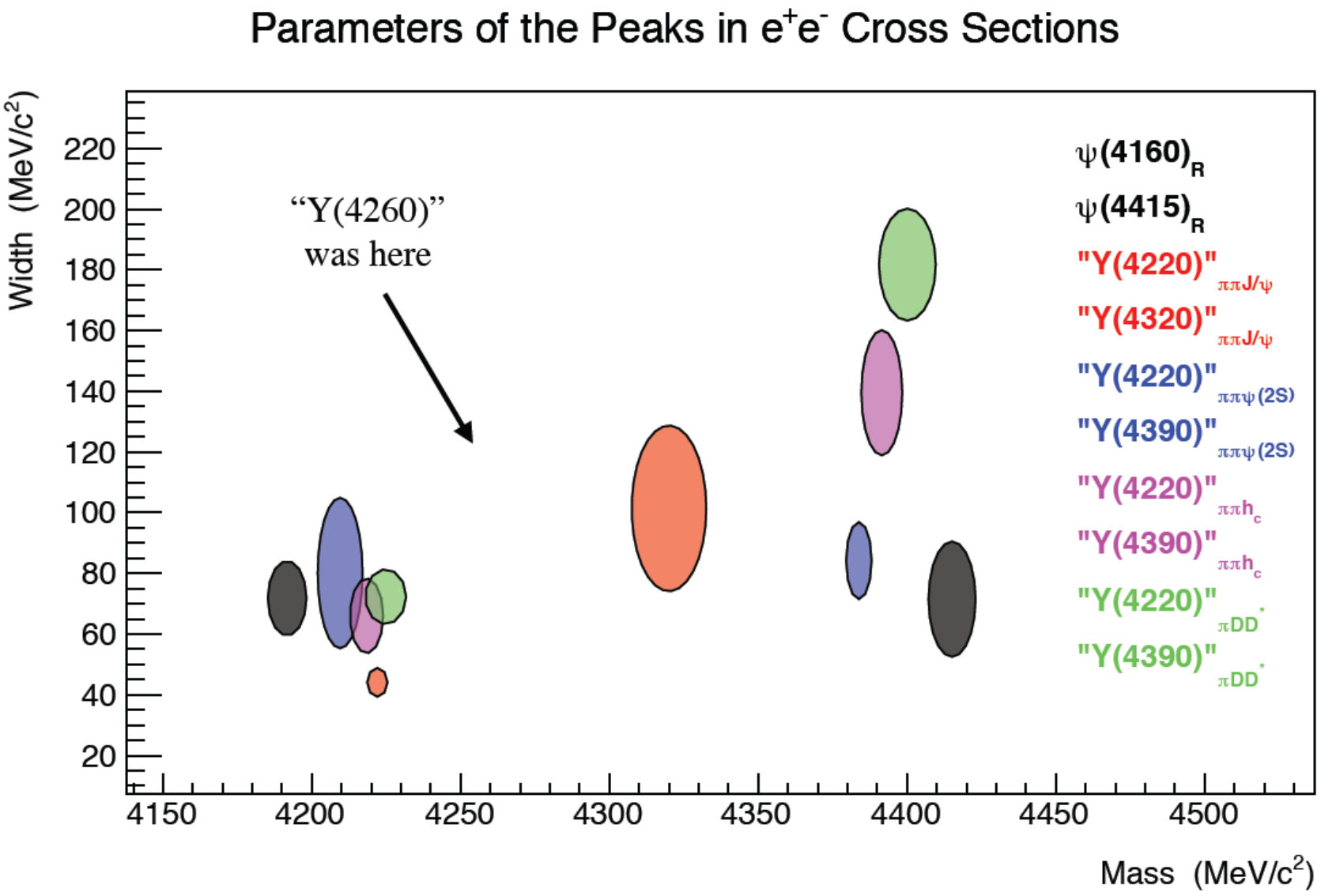




Y(4220) appeared in $\omega\chi_{c0}, \pi^+\pi^- J/psi, \pi^+\pi^-\psi', \pi^+\pi^- h_c, D^0D^{*-}\pi^+$

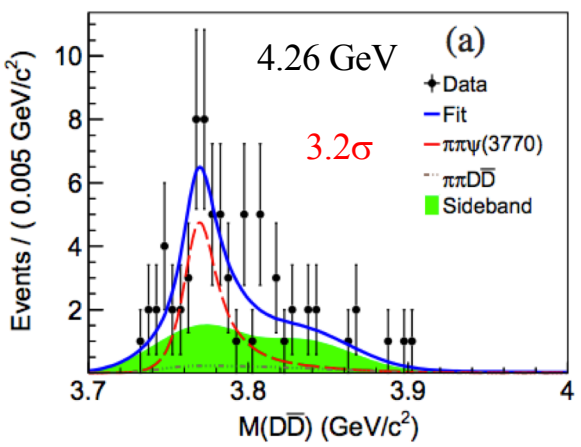
Mass~4220 MeV, Width~ 60 MeV!

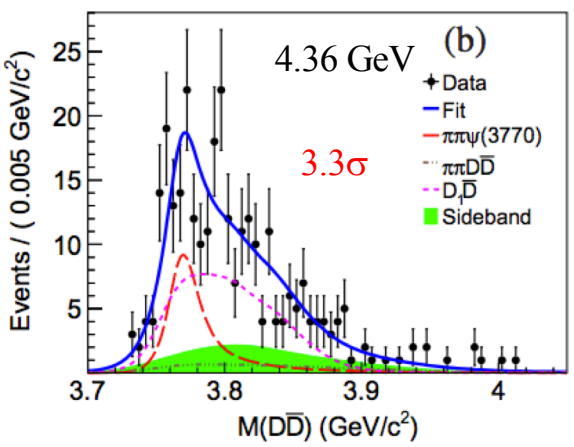
Y(4260)→Y(4220)

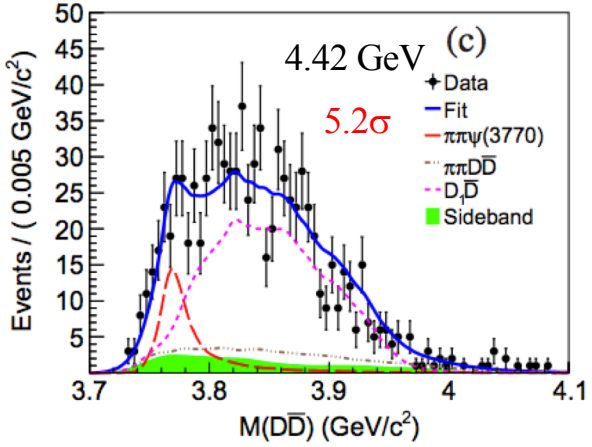

Parameters of the Peaks in e+e- Cross Sections
Width (MeV/c2)
Mass (MeV/c2)
"Y(4260)" was here
ψ(4160)R
ψ(4415)R
"Y(4220)" ππJ/ψ
"Y(4320)" ππJ/ψ
"Y(4220)" ππψ(2S)
"Y(4390)" ππψ(2S)
"Y(4220)" ππhc
"Y(4390)" ππhc
"Y(4220)" πDD*
"Y(4390)" πDD*

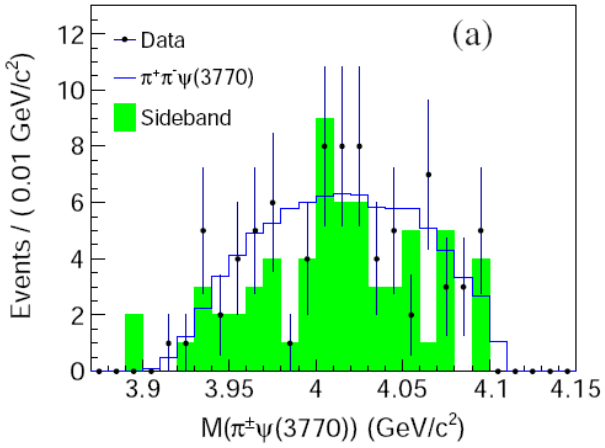
Submit to Phys. Rev. D; arXiv: 1903.08126v1 [hep-ex]

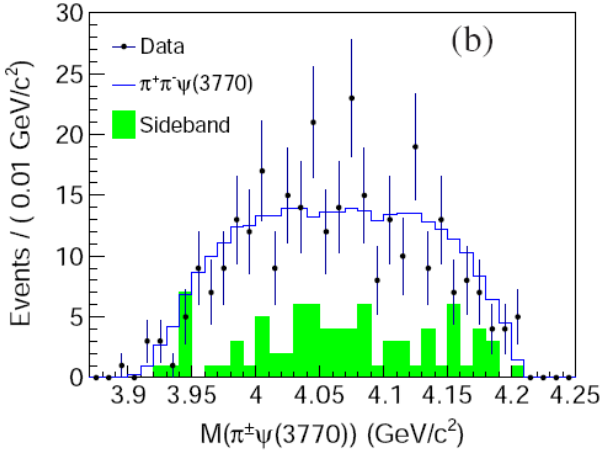
$e^+e^- \to \pi^+\pi^-\psi(3770)$

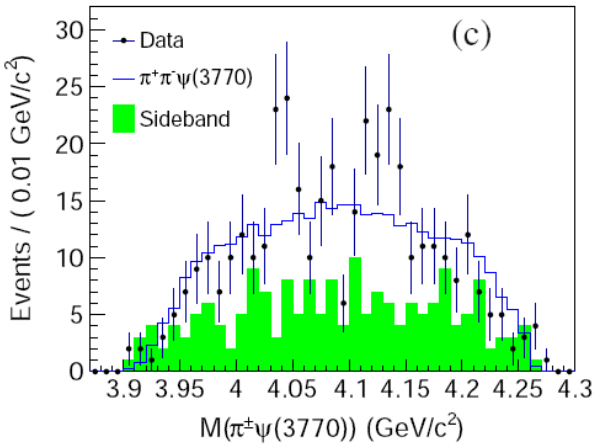








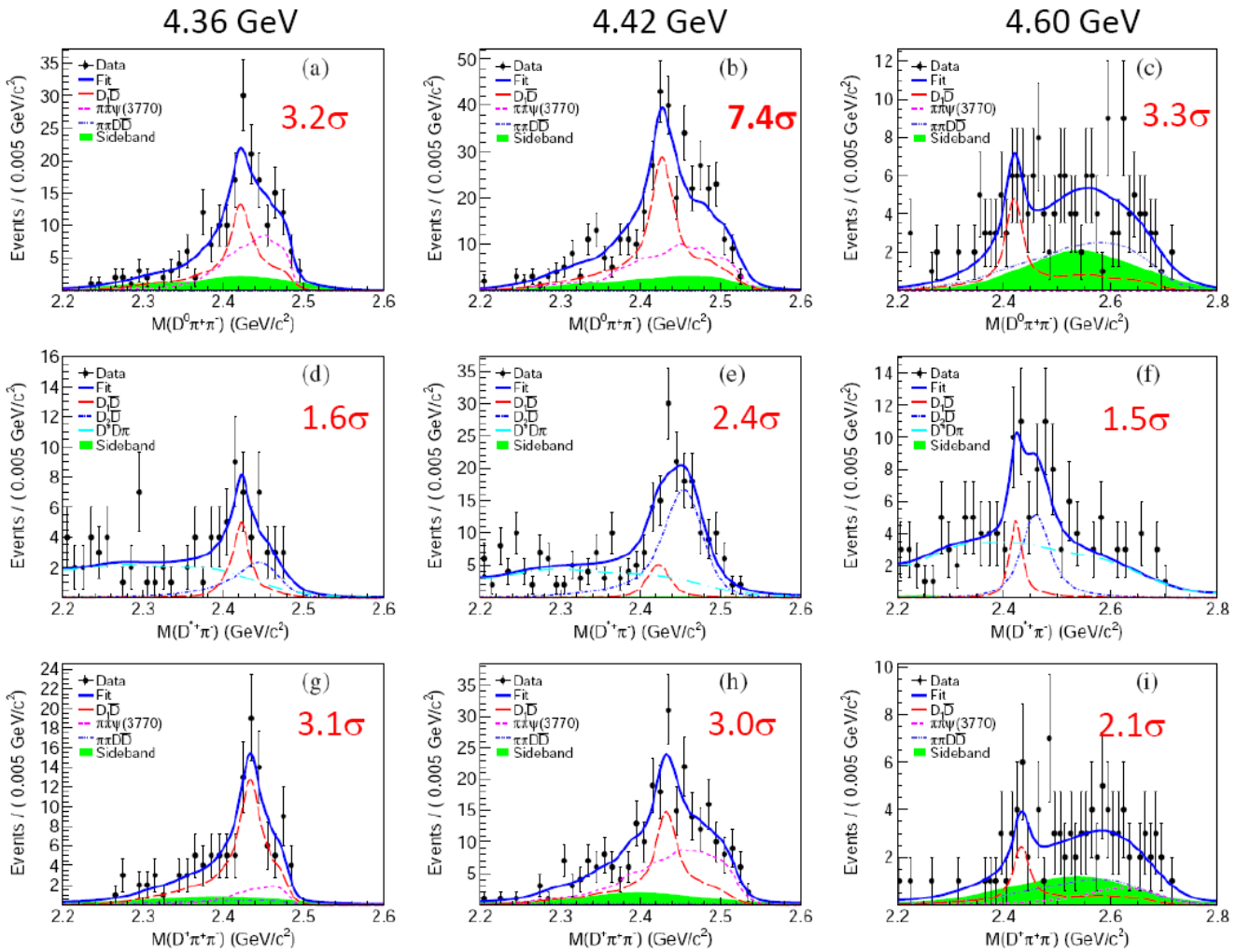




- **We observe $e^+e^- \to \pi^+\pi^-\psi(3770)$ for the first time at 4.42 GeV;**
- **There are hints for peaks at 4.04 and 4.13 GeV/c² at 4.42 GeV, while the statistical significance is low.**

Submit to Phys. Rev. D; arXiv: 1903.08126v1 [hep-ex]

$e^+e^- \to D_1(2420)\bar{D}$



Three different decay channels ($D^0\pi^+\pi^-$, $D^{*+}\pi^-$, and $D^+\pi^+\pi^-$) are used to search for $D_1(2420)$, the neutral mode with $D_1(2420)^0 \to D^0\pi^+\pi^-$ is reported with statistical significance of 7.4σ at 4.42 GeV.

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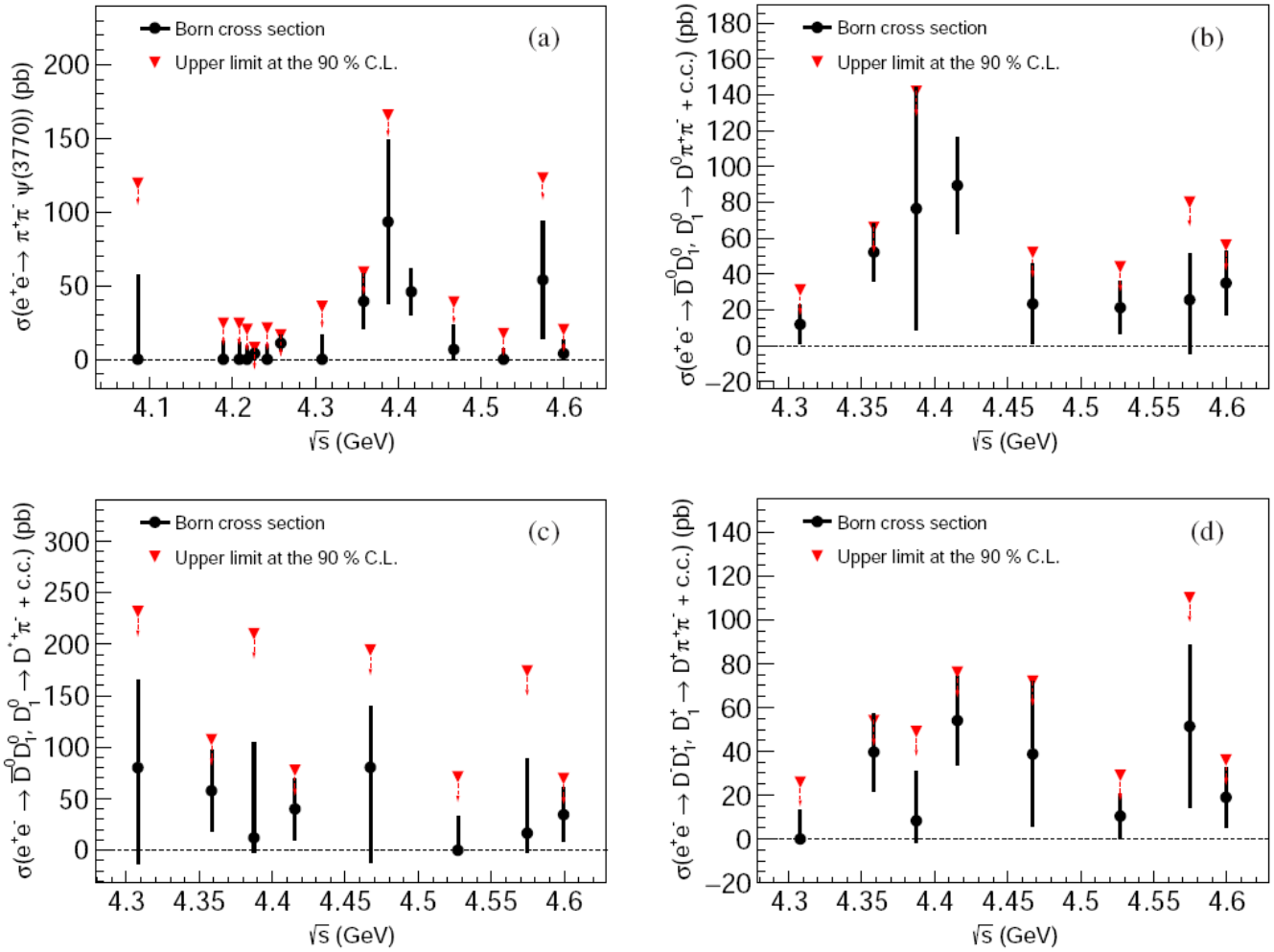
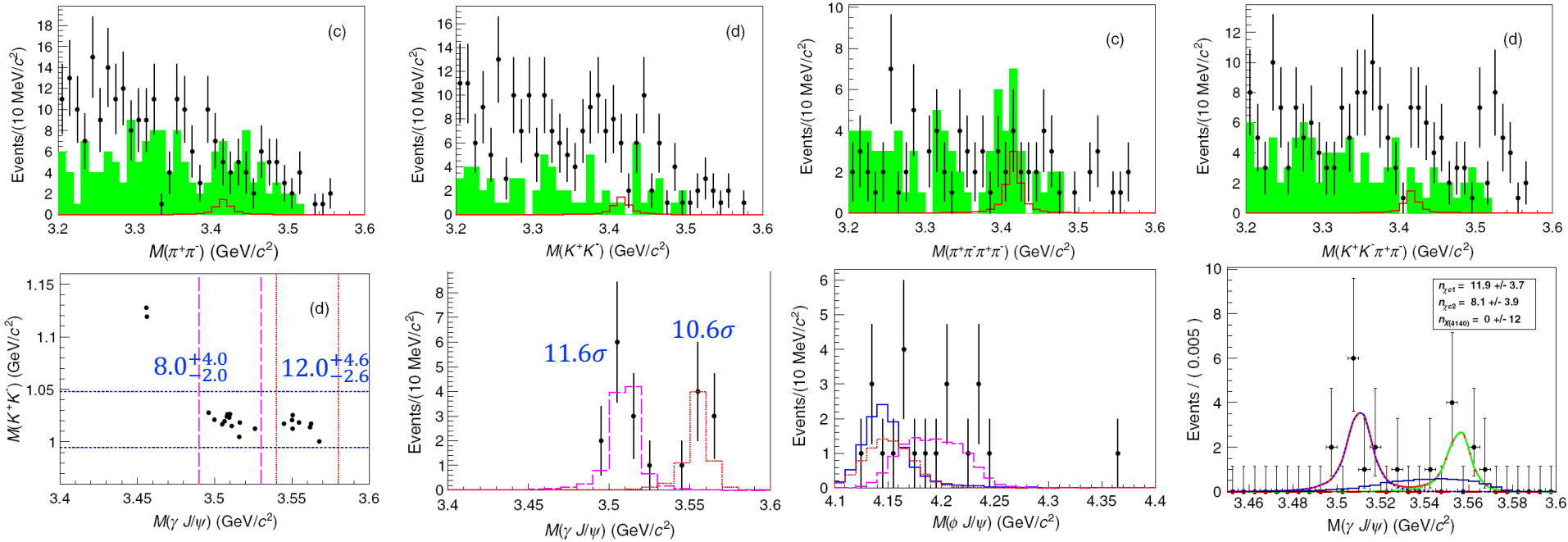
$e^+e^- \to D_1(2420)\bar{D}$



The Y(4390) or the $\psi(4415)$ resonance or from any other resonance cannot be distinguished based on the current statistics.

$e^+e^- \to \phi\chi_{cJ}$

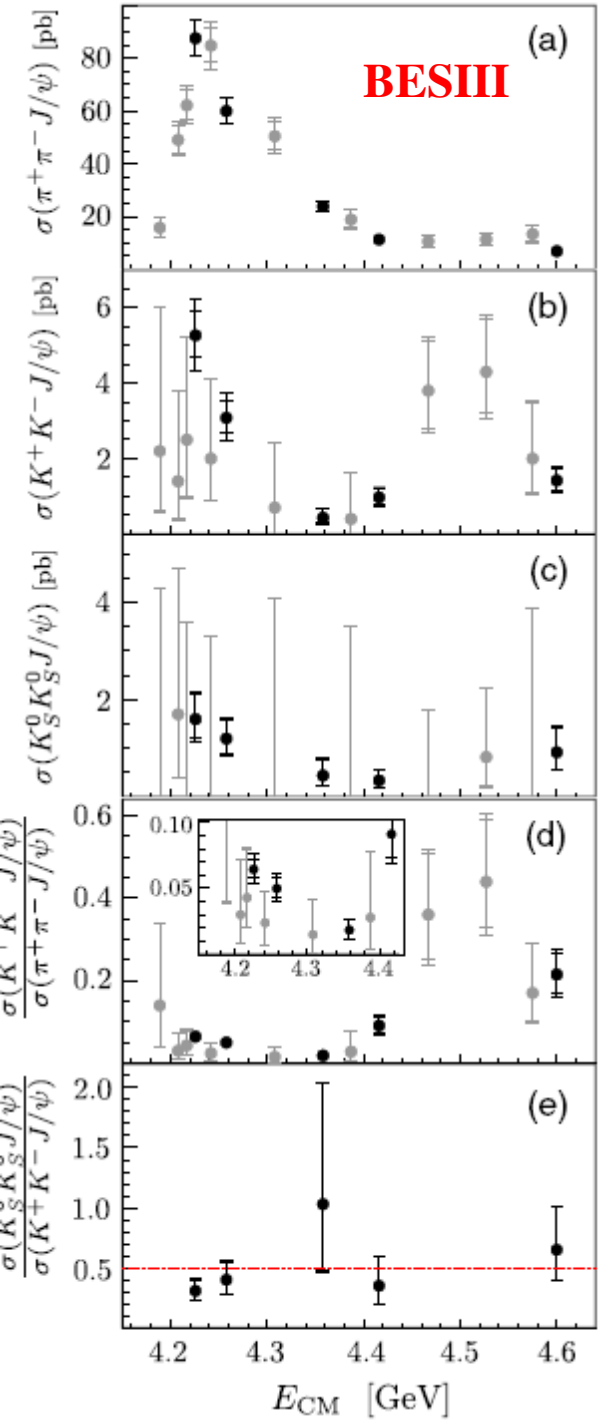
Phys. Rev. D 97, 032008 (2018)

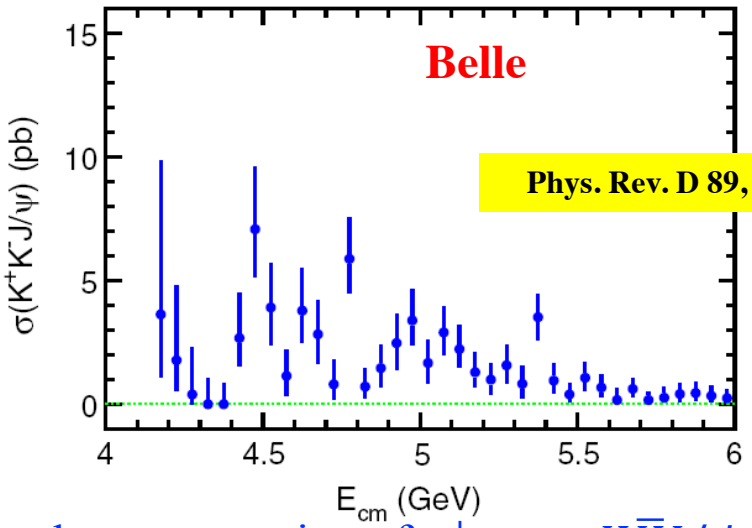


- We study the $e^+e^- \to \phi\chi_{c0,1,2}$ at $\sqrt{s} = 4.60$ GeV (567 pb^{-1}), where $\chi_{c0} \to \pi^+\pi^-, K^+K^-, K^+K^-\pi^+\pi^-$, and $\pi^+\pi^-\pi^+\pi^-$, $\chi_{c1,2} \to \gamma J/\psi, J/\psi \to \ell^+\ell^-(\ell = e\ or\ \mu)$, and $\phi \to K^+K^-$.
- No obvious $e^+e^- \to \phi\chi_{c0}$ signals are observed, the production $\sigma(e^+e^- \to \phi\chi_{c0}) < 5.4$ pb @ 90% C.L.;
- The first observation of $e^+e^- \to \phi\chi_{c1}$ and $\phi\chi_{c2}$, $\sigma(e^+e^- \to \phi\chi_{c1}) = 4.2^{+1.7}_{-1.0}$ pb and $\sigma(e^+e^- \to \phi\chi_{c2}) = 6.7^{+3.4}_{-1.7}$ pb;
- No obvious $e^+e^- \to \gamma Y(4140)$ signals are observed, $\sigma(e^+e^- \to \gamma Y(4140))\times\mathcal{B}(Y(4140) \to \phi J/\psi) <$ 1.2 pb @ 90% C.L..

Phys. Rev. D 97, 071101(R) (2018)

$e^+e^- \to K\bar{K}J/\psi$



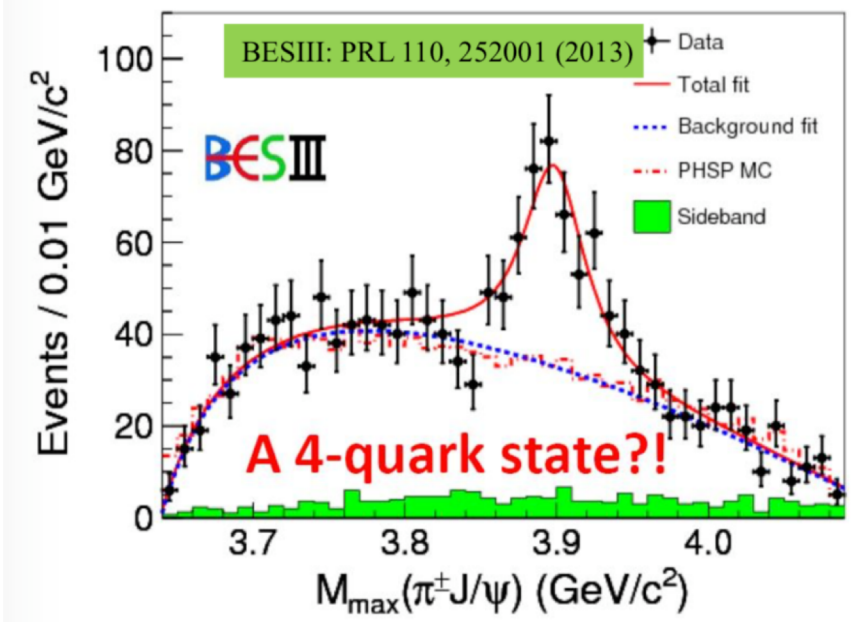


Phys. Rev. D 89, 072015 (2014)

- Measure the cross section of $e^+e^- \to K\bar{K}J/\psi$ at c.m. energies from 4.189 to 4.600 GeV.
- The energy dependence of the cross section for $e^+e^- \to K^+K^-J/\psi$ is shown to differ from that for $\pi^+\pi^-J/\psi$ in the region around the Y(4260);
- The ratio of cross sections for $e^+e^- \to K^+K^-J/\psi$ and $e^+e^- \to K_S^0K_S^0J/\psi$ is consistent with expectations from isospin conservation.

The Z_c states

Observation of Zc(3900)



$Z_c(3900)^+$:

$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$

$\Gamma = (46 \pm 10 \pm 20)\ \mathrm{MeV}$

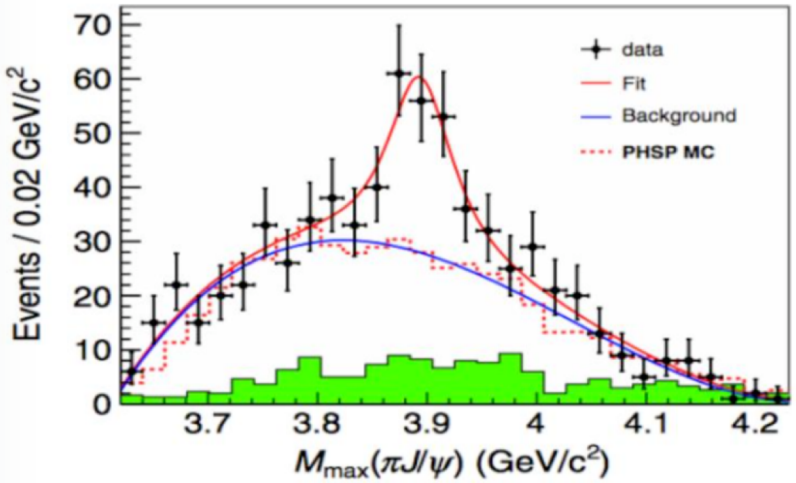
Mass close to $D\bar{D}^*$ threshold

Decays to J/ψ → contains $c\bar{c}$
Electric charge → contains $u\bar{d}$

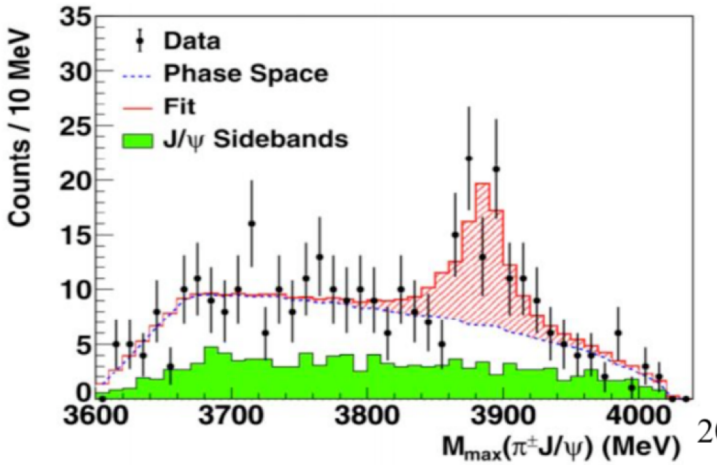
$\sigma[e^+e^- \to \pi^+\pi^- J/\psi] = 62.9 \pm 1.9 \pm 3.7$ pb at 4.26 GeV

$\frac{\sigma[e^+e^- \to \pi^\pm Z_c(3900)^\mp \to \pi^+\pi^- J/\psi]}{\sigma[e^+e^- \to \pi^+\pi^- J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\%$ at 4.26 GeV

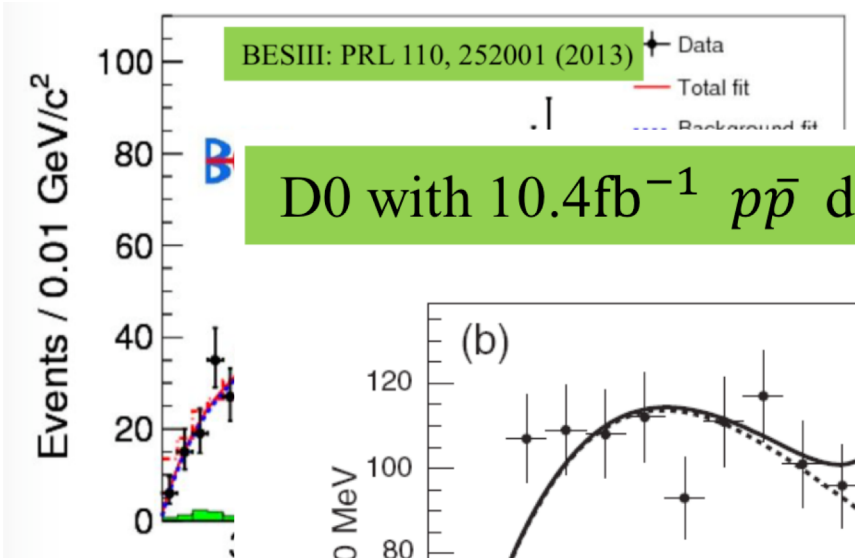
Belle with ISR data (PRL110,252002)



CLEOc data at 4.17 GeV (PLB 727,366)



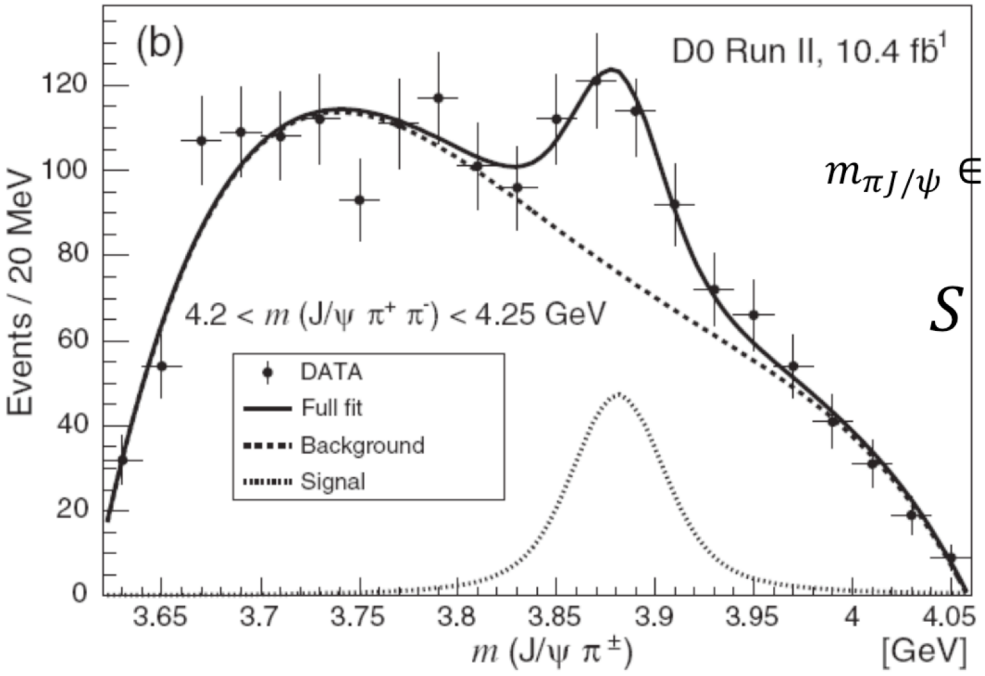
Observation of Zc(3900)



$Z_c(3900)^+$:

$m = (3899.0 \pm 3.6 \pm 4.9)\ \mathrm{MeV}/c^2$

D0 with 10.4fb^{-1} $p\bar{p}$ data (PRD98, 052010 (2018))



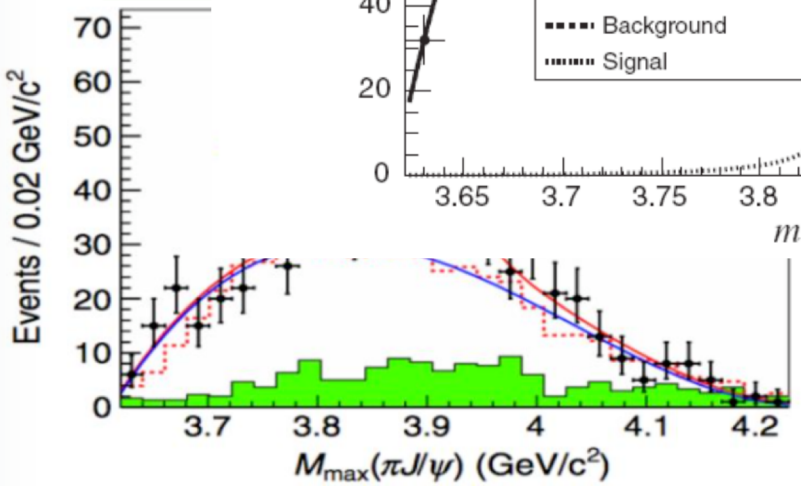
$m_{\pi J/\psi} \in [4.2,4.7]$ GeV

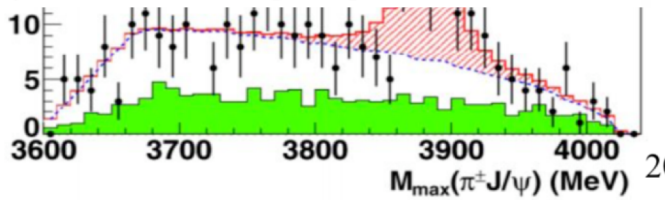
$S = 5.6\sigma$

at 4.26 GeV

Belle

6

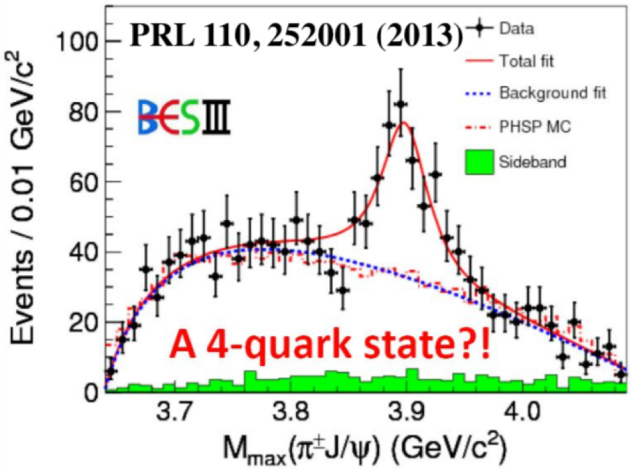




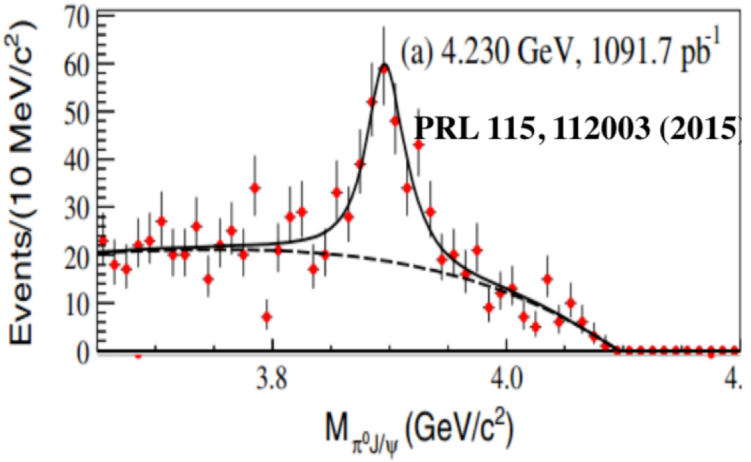
20

Observation of Zc(3900)

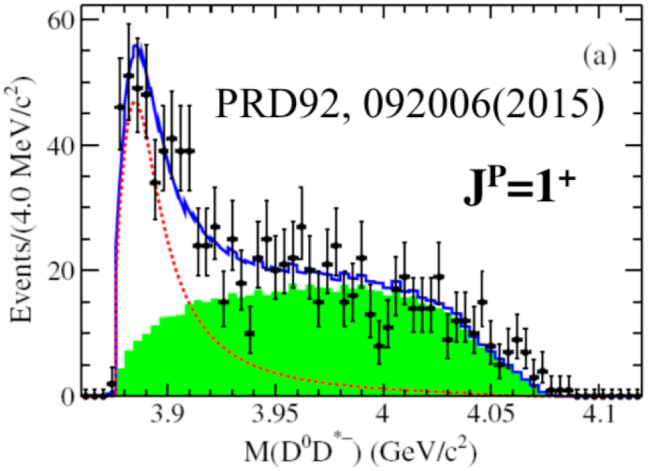
$Z_c(3900)^{\pm} : e^+e^- \to \pi^+\pi^- J/\psi$



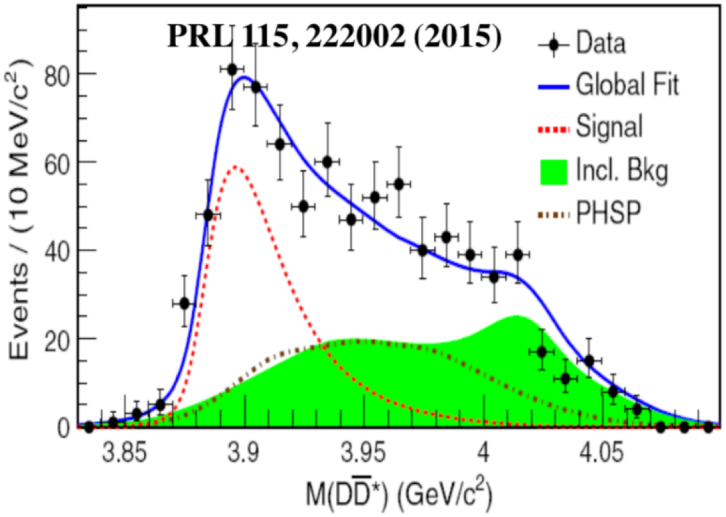
$Z_c(3900)^{0} : e^+e^- \to \pi^0\pi^0 J/\psi$



$Z_c(3900)^{\pm} : e^+e^- \to \pi^{\pm}(D\bar{D}^*)^{\mp}$

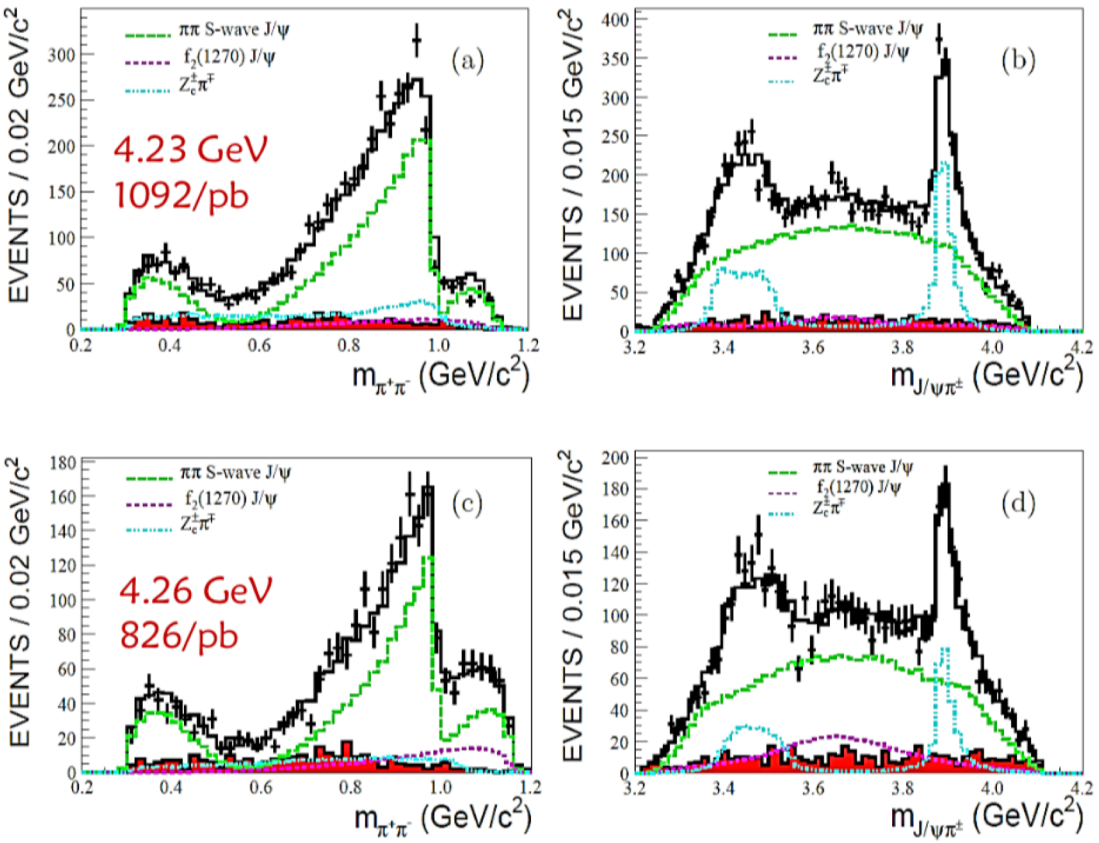


$Z_c(3900)^{0} : e^+e^- \to \pi^0(D\bar{D}^*)^0$



Spin-parity of $Z_c(3900)$

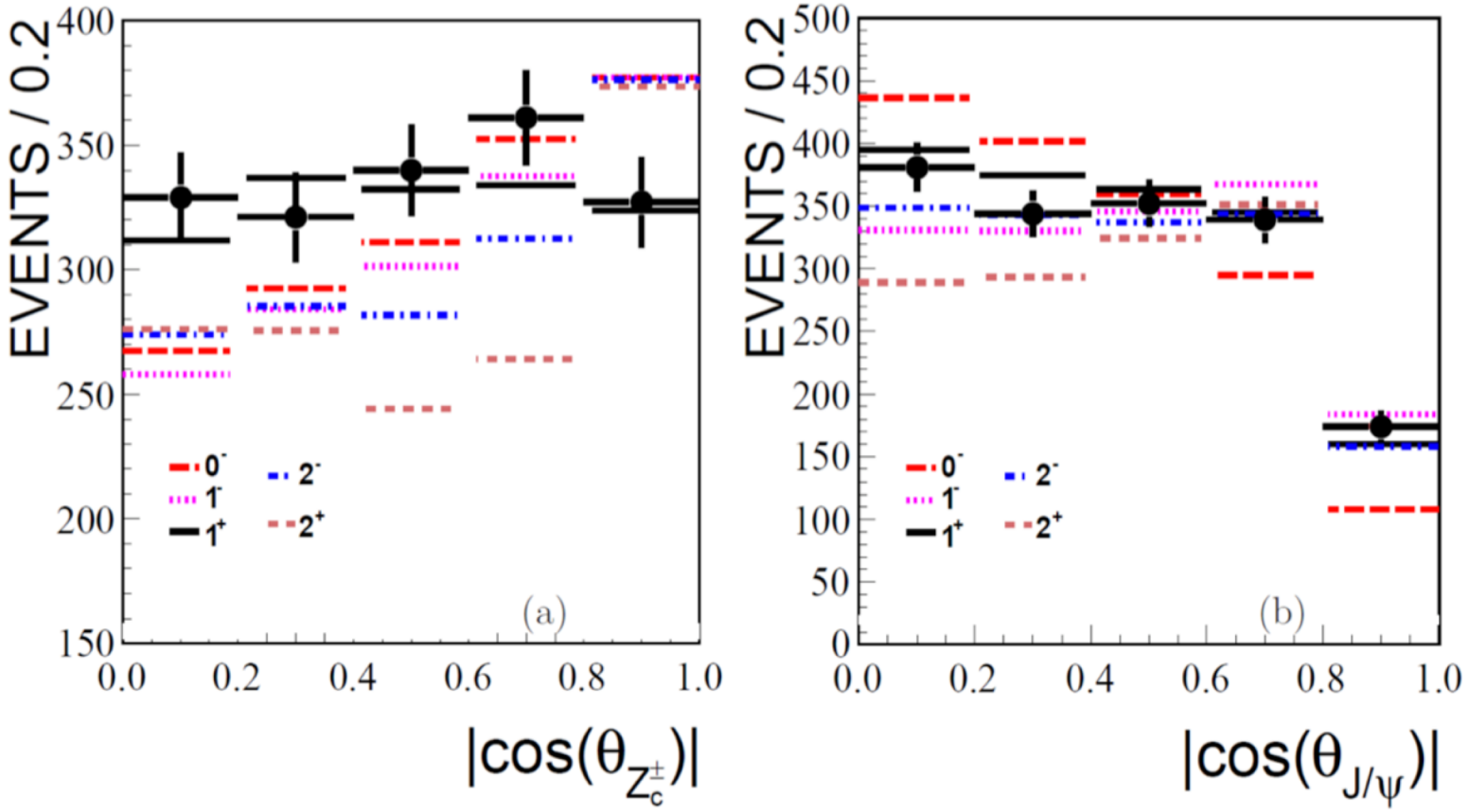
PRL 119, 072001 (2017)



- Asymmetric line shape
- JP=1+ preferred over 0-, 1-, 2-, 2+ by at least 7σ.
- Significant $f_0(980)$ contribution
- ππ D-wave fraction increases as E_{cm} increases

Spin-parity of $Z_c(3900)$

PRL 119, 072001 (2017)

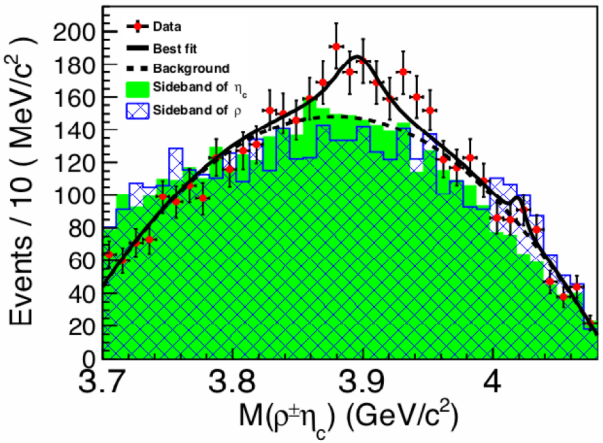


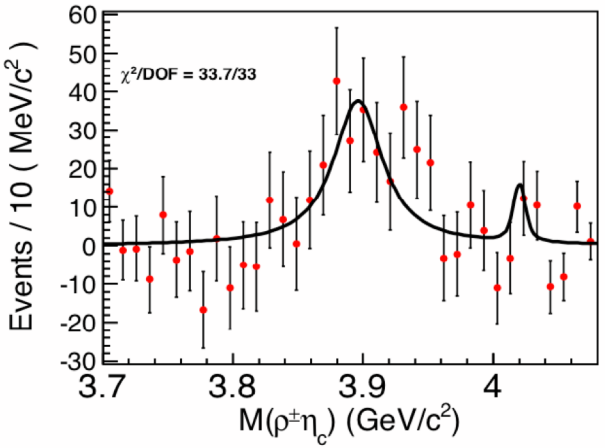
- Z_c enhanced events show clear JP=1+ preference!

$Z_c(3900) \to \rho\eta_c$

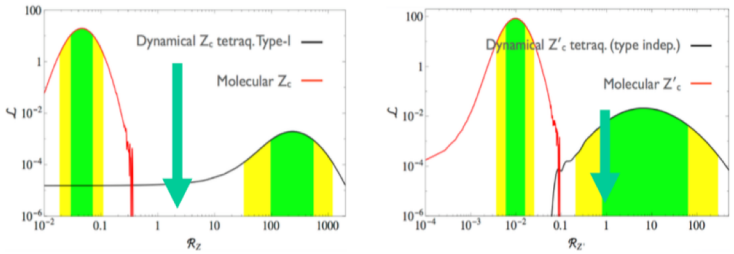
arXiv: 1906.00831

Decay mode	BR
$\eta_c \to p\bar{p}$	~0.13%
$\eta_c \to 2(K^+K^-)$	~0.15%
$\eta_c \to \pi^+\pi^-K^+K^-$	~1.50%
$\eta_c \to K^+K^-\pi^0$	~1.20%
$\eta_c \to p\bar{p}\pi^0$	~0.18%
$\eta_c \to K_SK\pi$	~1.80%
$\eta_c \to \pi^+\pi^-\eta$	~1.60%
$\eta_c \to K^+K^-\eta$	~0.57%
$\eta_c \to \pi^+\pi^-\pi^0\pi^0$	~2.40%





Strong evidence of $e^+e^- \to \pi Z_c$, $Z_c \to \rho\eta_c$ is observed at $\sqrt{s} = 4.226$, statistical significance is 4.3σ.



$$R_z = \frac{B(Z_c \to \rho\eta_c)}{B(Z_c \to \pi J/\psi)} \qquad R_{z'} = \frac{B(Z_c' \to \rho\eta_c)}{B(Z_c' \to \pi h_c)}$$

A.Esposito et al, Phys. Lett. B 746, 194 (2015)

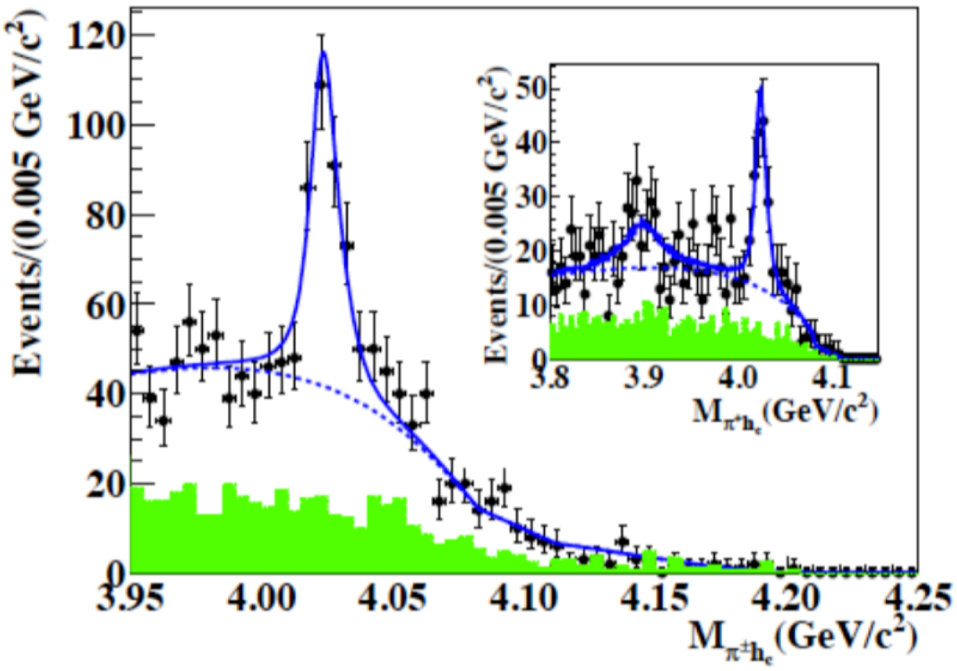
Also calculations predict very different values:

$R_z = 10^{-3} \sim 10^2$!

arXiv:1806.05651
arXiv:1512.01938
PRD 91, 034032 (2015)
PRD 90, 054006 (2014)
EPJC 73, 2561 (2013)

	$\sqrt{s} = 4.226$ GeV	$\sqrt{s} = 4.258$ GeV	$\sqrt{s} = 4.358$ GeV	Type-I	Type-II	Molecule
$R_{Z_c(3900)}$	2.2 ± 0.9	< 5.6	...	230^{+330}_{-140}	$0.27^{+0.40}_{-0.17}$	$0.046^{+0.025}_{-0.017}$
$R_{Z_c(4020)}$	< 1.6	< 0.9	< 1.4	$6.6^{+56.8}_{-5.8}$		$0.010^{+0.006}_{-0.004}$

Observation of $Z_c(4020)^+$



BESIII: PRL111, 242001

Simultaneous fit to 4.23/4.26/4.36 GeV data, 16 η_c decay modes. 8.9σ

$M(Z_c(4020)) =$

$4022.9\pm0.8\pm2.7$ MeV;

$\Gamma(Z_c(4020)) =$

$7.9\pm2.7\pm2.6$ MeV

Close to $\bar{D}^*D^*$ threshold

$\sigma(e^+e^- \rightarrow \pi Z_c \rightarrow \pi^+\pi^- h_c)$:

$8.7\pm1.9\pm2.8\pm1.4$ pb @ 4.230 GeV

$7.4\pm1.7\pm2.1\pm1.2$ pb @ 4.260 GeV

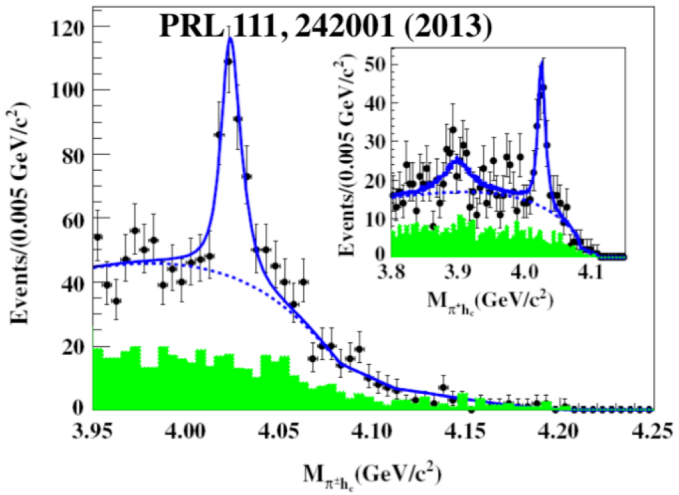
$10.3\pm2.3\pm3.1\pm1.6$ pb @ 4.360 GeV

Significance: 8.9σ [$Z_c(4020)$]

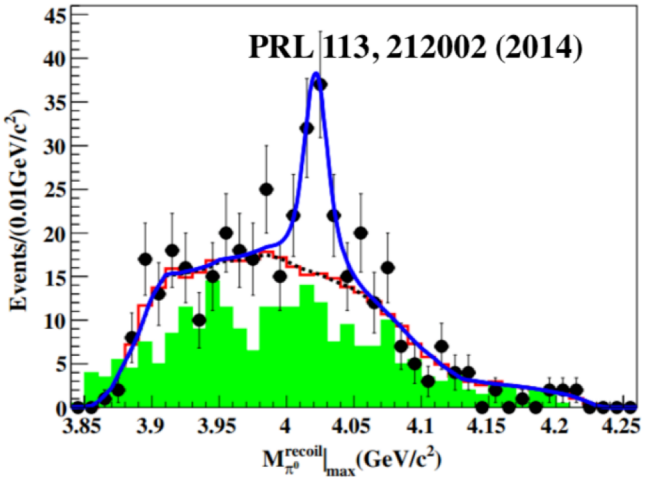
No significant $Z_c(3900)$ (2.1σ)

Observation of Zc(4020/4025)

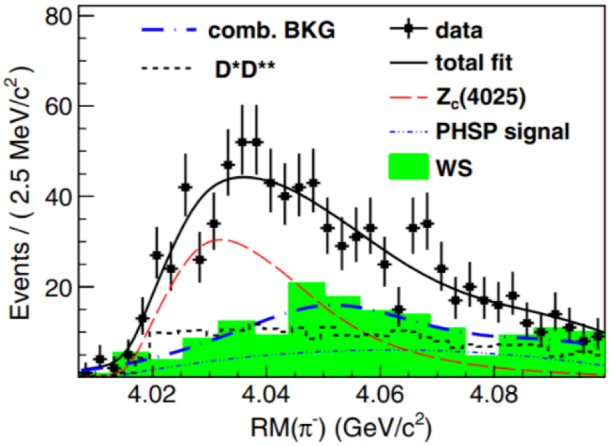
$Z_c(4020)^{\pm} : e^+e^- \to \pi^+\pi^- h_c$



$Z_c(4020)^0 : e^+e^- \to \pi^0\pi^0 h_c$

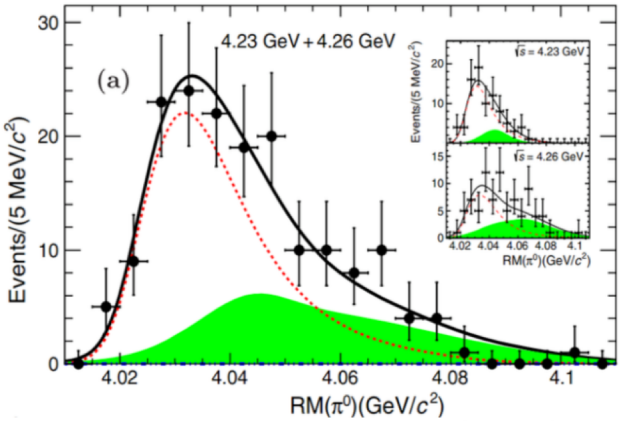


$Z_c(4020)^{\pm} : e^+e^- \to \pi^{\pm}(D^*\bar{D}^*)^{\mp}$



PRL 112, 132001 (2014)

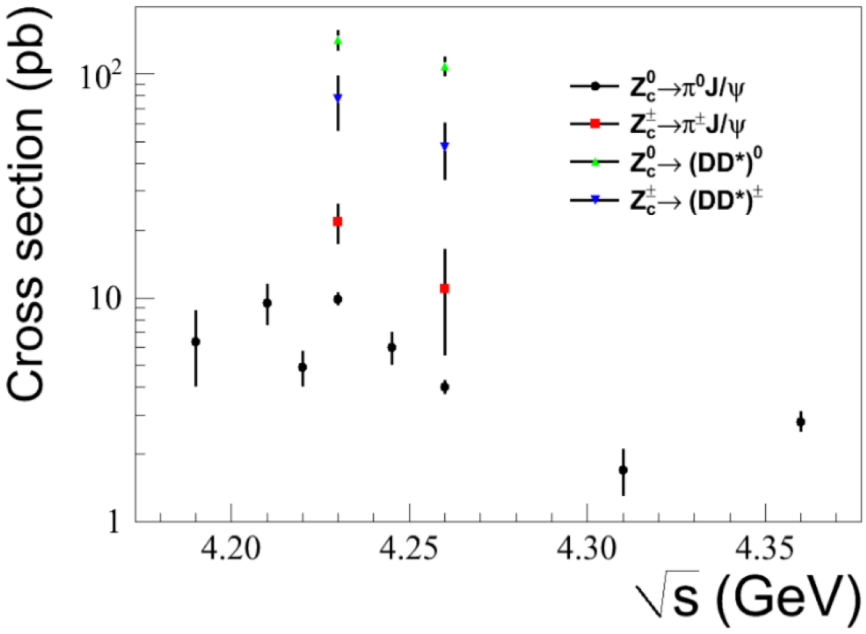
$Z_c(4020)^0 : e^+e^- \to \pi^0(D^*\bar{D}^*)^0$



PRL 115, 182002 (2015)

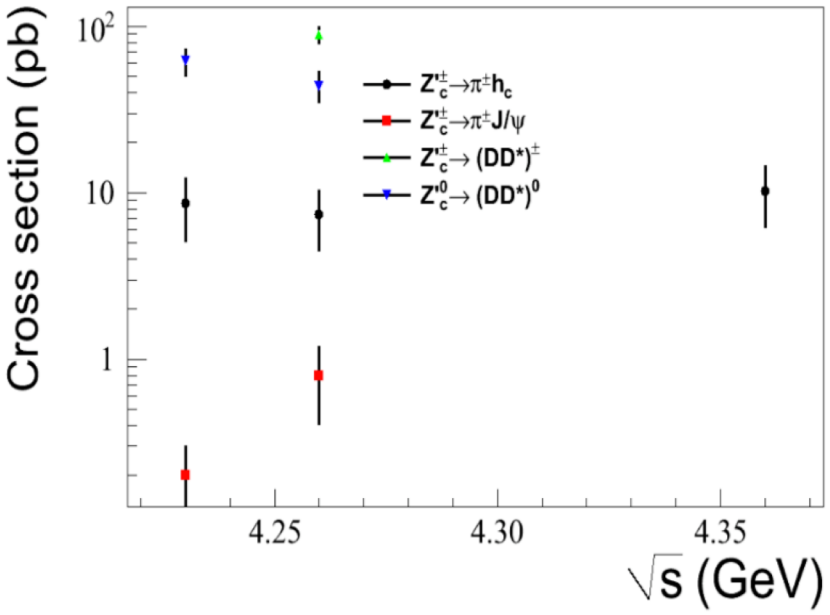
Zc(3900)/Zc(4020) production cross section

$e^+e^- \to \pi^{\mp} Z_c^{\pm}, \pi^0 Z_c^0,$



$Z_c(3900)^{\pm} \to (DD^*)^{\pm}$, PRD92, 092006
$Z_c(3900)^0 \to \pi^0 J/\psi$, PRL115, 112003
$Z_c(3900)^{\pm} \to \pi^{\pm} J/\psi$, PRL119, 072001

$e^+e^- \to \pi^{\mp} Z'^{\pm}_c, \pi^0 Z'^0_c,$



$Z_c'(4020)^{\pm} \to \pi^{\pm} h_c$, PR111, 242001
$Z_c'(4020)^{\pm} \to \pi^{\pm} J/\psi$: PRL119, 072001
$Z'_c(4020)^{\pm} \to (D^* D^*)^{\pm}$: PRL112, 132001
$Z_c'(4020)^0 \to (D^* D^*)^0$: PRL115, 182002

Z_c in $e^+e^- \to \pi^+\pi^-\psi'$?

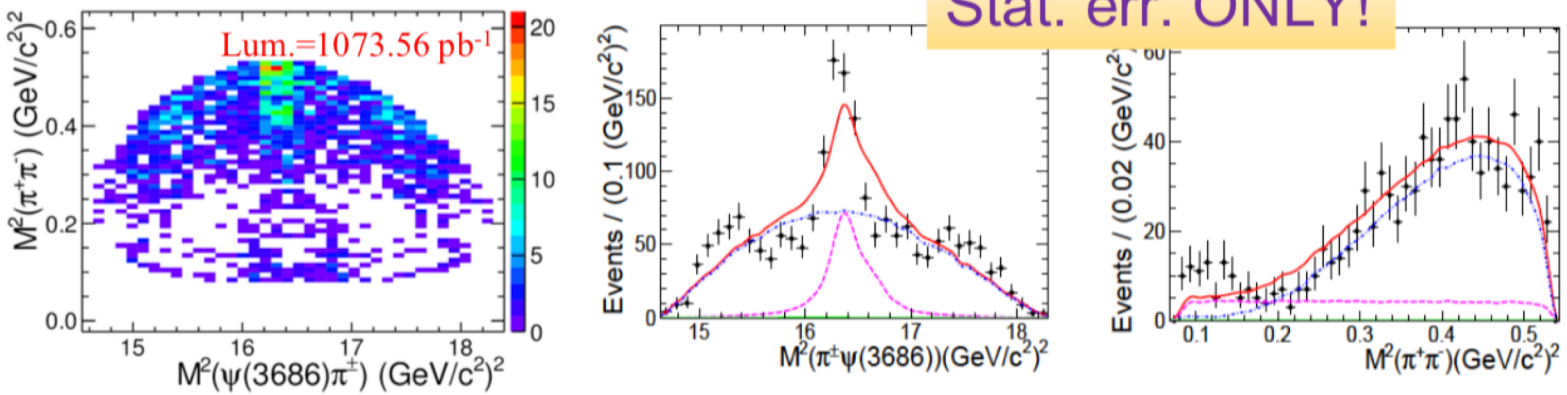
PRD 96, 032004 (2017)

- A prominent narrow structure is observed in $\pi\psi(3686)$ mass spectrum for data at $\sqrt{s} = 4.416$ GeV.
- An S-wave Breit-Wigner fit function is performed on the Dalitz plot of $M^2(\pi^+\psi(3686))$ versus $M^2(\pi^-\psi(3686))$

$$\frac{p \cdot q/c^2}{(M_R^2 - x)^2 + M_R^2 \cdot \Gamma^2/c^4} + \frac{p \cdot q/c^2}{(M_R^2 - y) + M_R^2 \cdot \Gamma^2/c^4}$$

- The fit yields a mass of $M=4032.1 \pm 2.4\ \mathrm{MeV}/c^2$ and a width of $\Gamma=26.1 \pm 5.3$ MeV, with a significance of 9.2σ

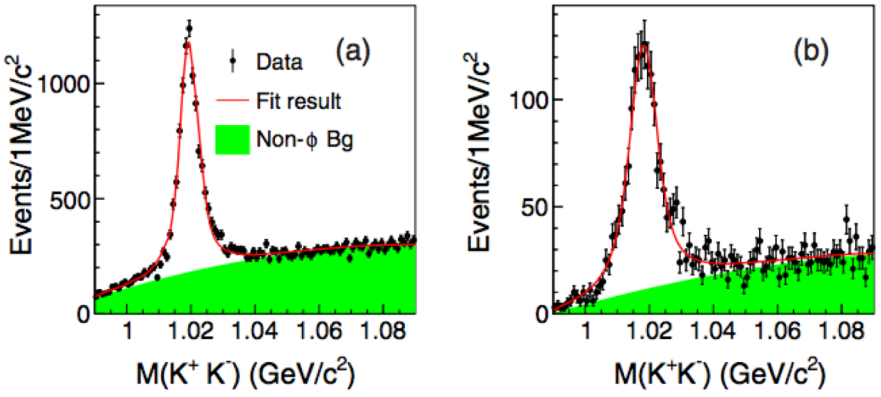
Stat. err. ONLY!

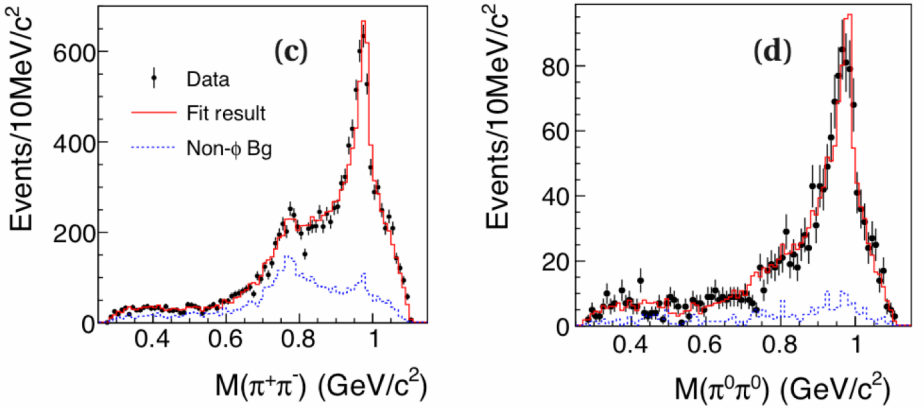


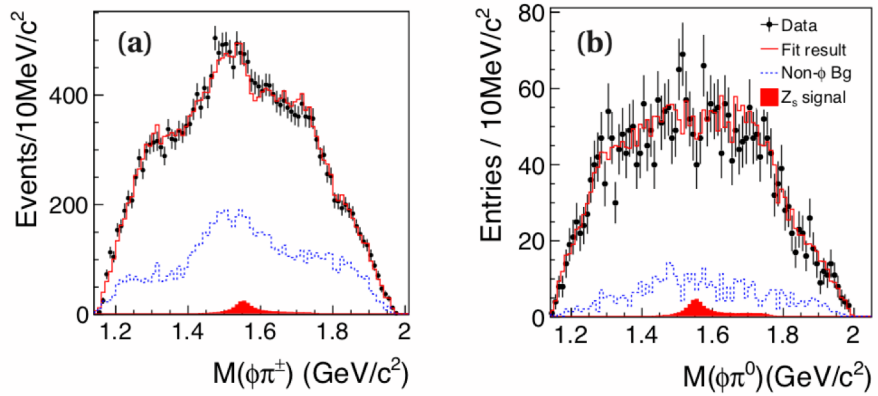
Different behavior between high and low $M^2(\pi^+\pi^-)$!

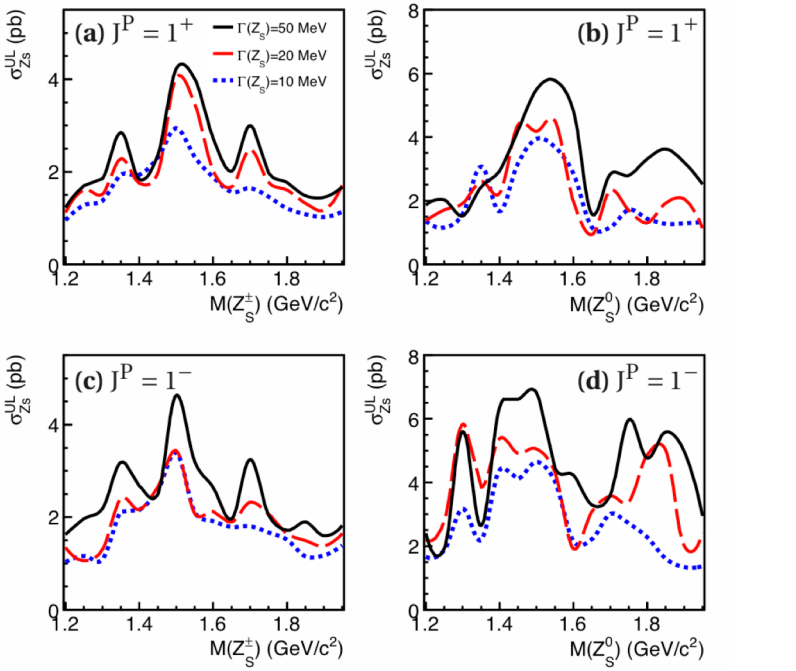
Search for a strangeonium-like structure Z_s decaying into $\phi\pi$ and a measurement of the cross section $e^+e^- \to \phi\pi\pi$

Phys. Rev. D **99**, 011101(R)









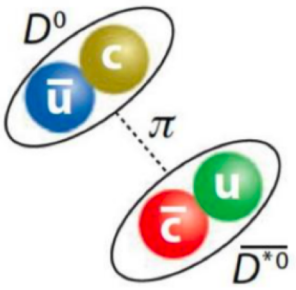
- PWA is performed.
- NO Zs signal observed and upper limit is given.

The X state

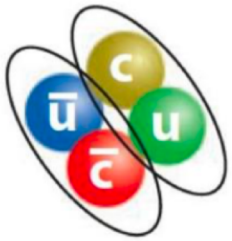
What have we known about X(3872)?

- Mass
  - $3871.68 \pm 0.17\ \mathrm{MeV}/c^2$
  - $B_E = 0.01 \pm 0.20\ \mathrm{MeV}/c^2$
- Width
  - $< 1.2\ \mathrm{MeV}$
- $J^{PC} = 1^{++}$
- Production
  - In $pp/p\bar{p}$ collision
  - In B decays
  - In Y decays
- Decay
  - $\pi^+\pi^- J/\psi$ and $\omega J/\psi$
  - $\gamma J/\psi$ and $\gamma\psi(3686)$
  - $D^0\bar{D}^{*0} + c.c.$

- What is it?
  - **Loosely $D^0\bar{D}^{0*}$ bound state?**
  - **Mixture of $\chi_{c1}{}'$ and $D^0\bar{D}^{0*}$?**
  - **Cusp?**
  - **Tetraquarks?**

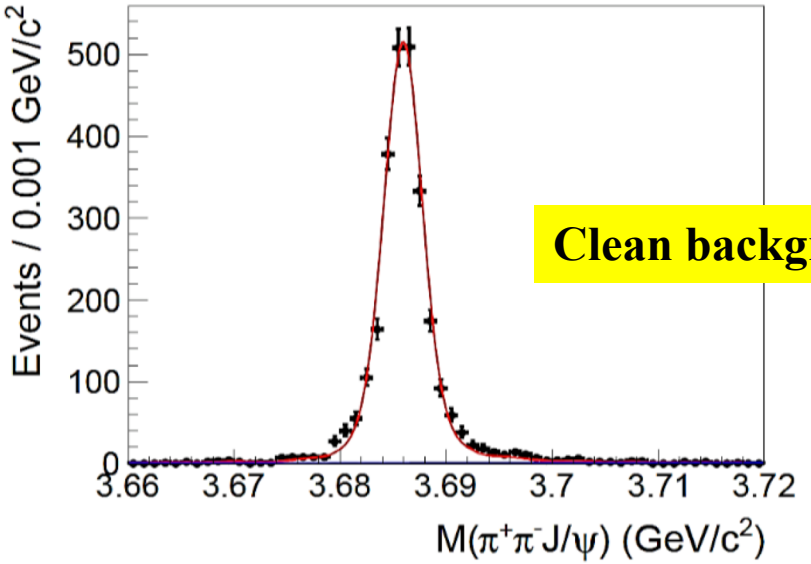


D^0–$\bar{D}^{*0}$ "molecule"

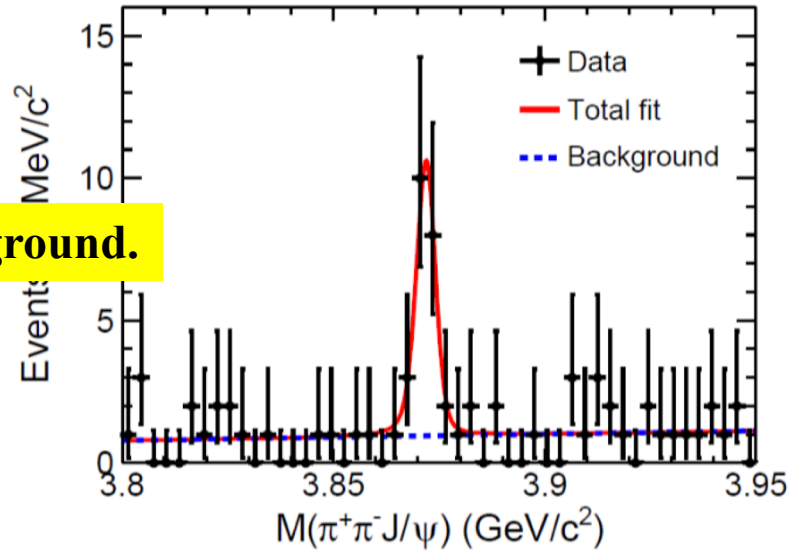


Diquark–diantiquark

Observation of $e^+e^- \to \gamma X(3872)$



Clean background.



ISR ψ' signal is used for mass, and mass resolution calibration.

N=1818; ΔM=0.34±0.04 MeV; $\Delta\sigma_M$=1.14 ±0.07 MeV

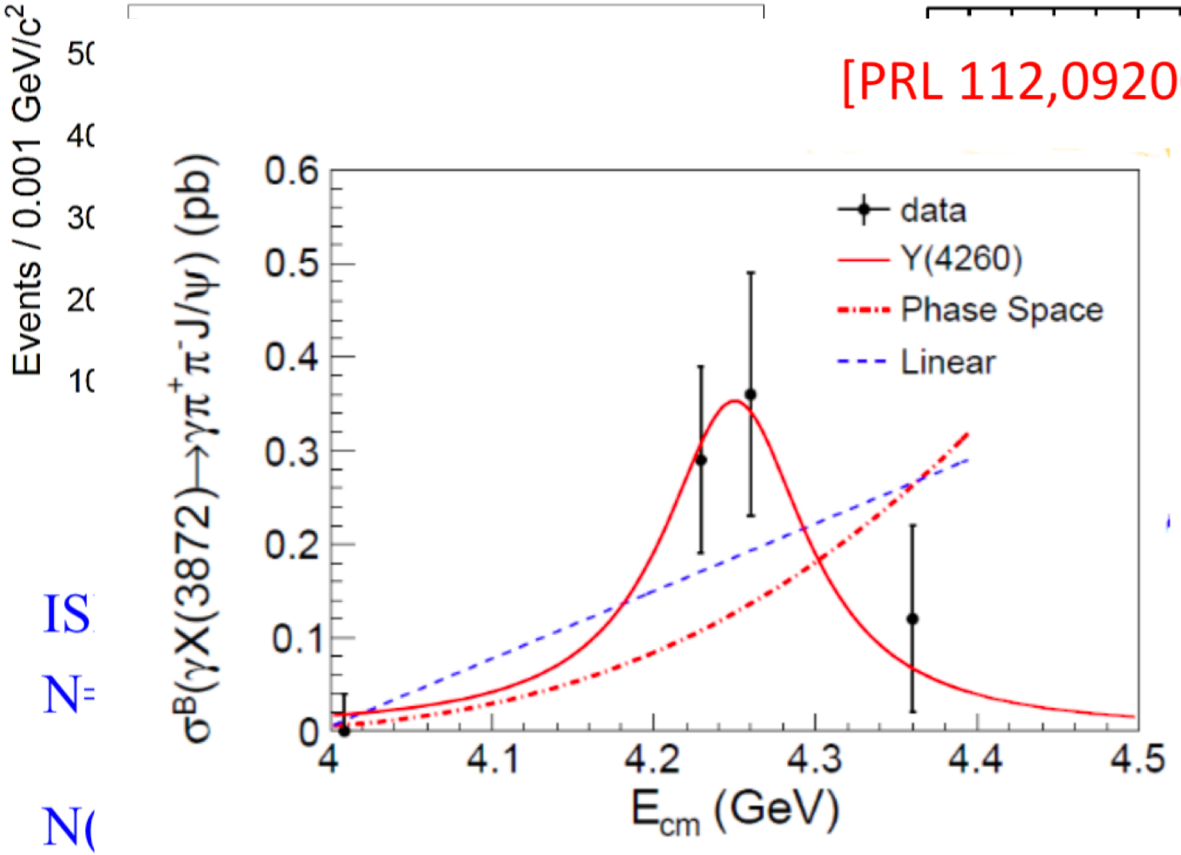
N(X(3872)) = 20.1±4.5 **6.3σ**

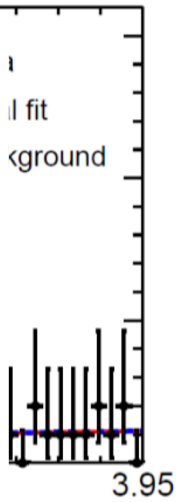
PRL 112, 092001 (2014)

M(X(3872)) = 3871.9±0.7±0.2 MeV [PDG: 3871.68 ±0.17 MeV]

Observation of $e^+e^- \to \gamma X(3872)$

[PRL 112,092001(2014)]





IS … n.

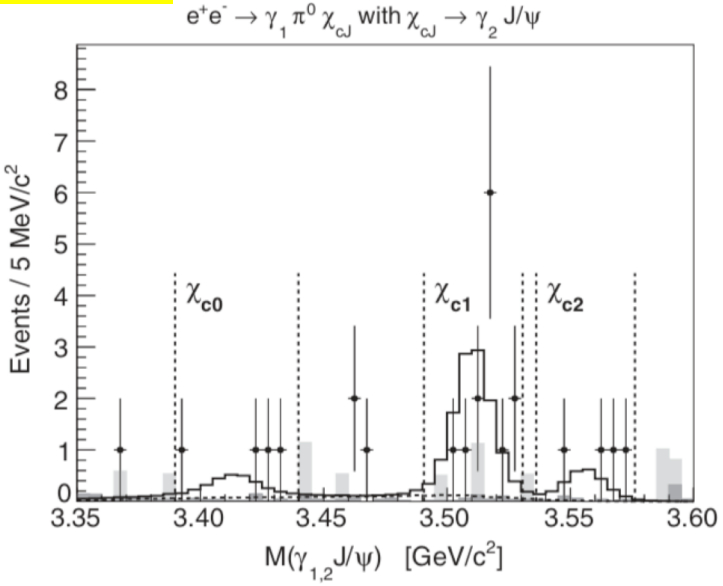
N= …

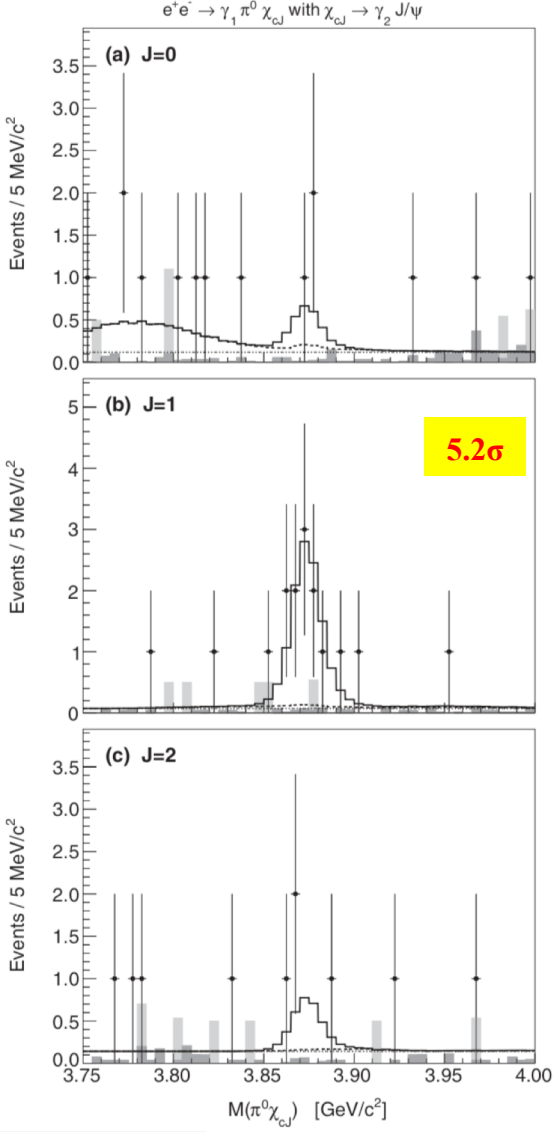
N(… (2014)

M(X(3872)) = 3871.9±0.7±0.2 MeV [PDG: 3871.68 ±0.17 MeV]

$X(3872) \to \pi^0 \chi_{cJ}$

PRL 122,202001(2019)



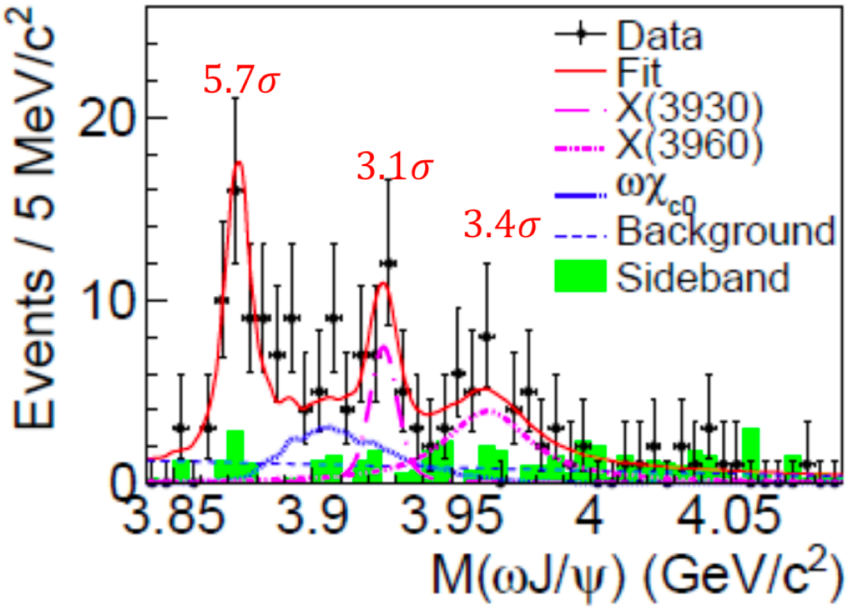


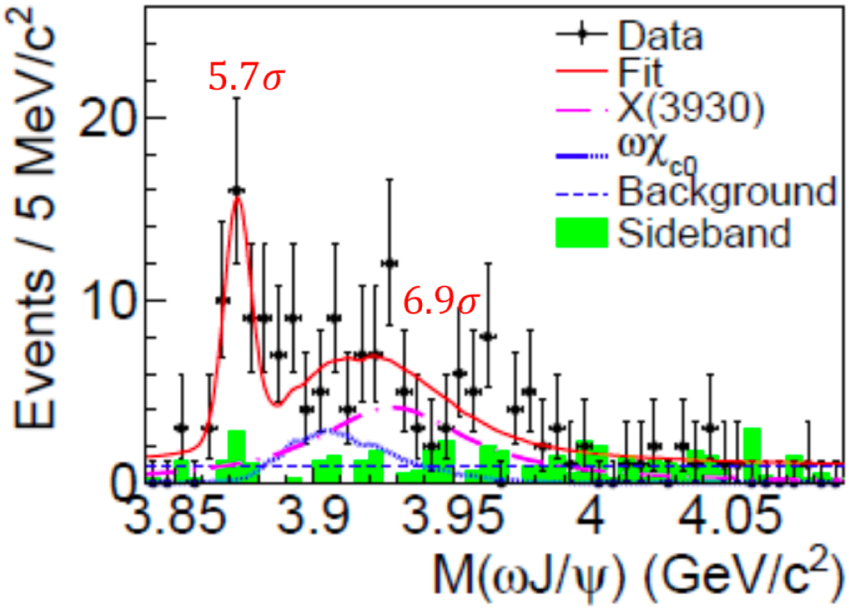
- observation of $\chi_{c1}(3872) \to \pi^0 \chi_{c1}$ with 5.2 σ, no signal for $\chi_{c0,2}$
- $R_J = \frac{Br(\chi_{c1}(3872) \to \pi^0 \chi_{cJ})}{Br(\chi_{c1}(3872) \to \pi^+\pi^- J/\psi)}$ with $R_0 < 19$ (90% CL), $R_1 = 0.88^{+0.33}_{-0.27} \pm 0.10$, $R_2 < 1.1$ (90% CL)

- PRD 77, 014013 (2008): $\Gamma(\chi_{c1}(3872) \to \pi^0 \chi_{c1}) \sim 0.06$ keV in case of a conventional $c\bar{c}$
- combining $3.2\% < Br(\chi_{c1}(3872) \to \pi^+\pi^- J/\psi) < 6.4\%$ with $R_1 = 0.88$ would imply $c\bar{c}$-state with $\Gamma_{tot}(\chi_{c1}(3872)) \sim 1.0 - 2.0$ keV → strongly disfavors $c\bar{c}$ interpretation

$e^+e^- \to \gamma X, X \to \omega J/\psi$

BESIII, PRL122, 232002 (2019)

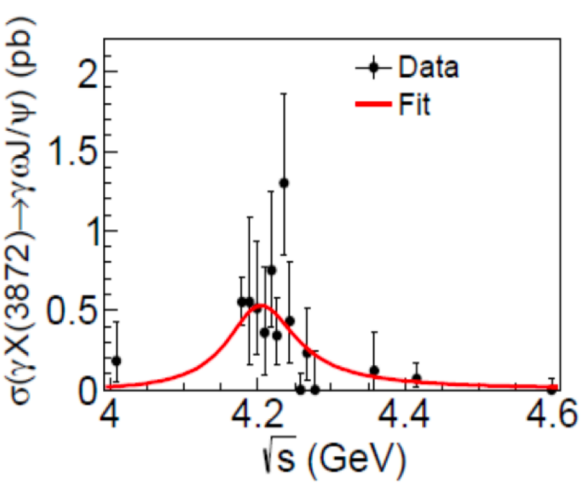


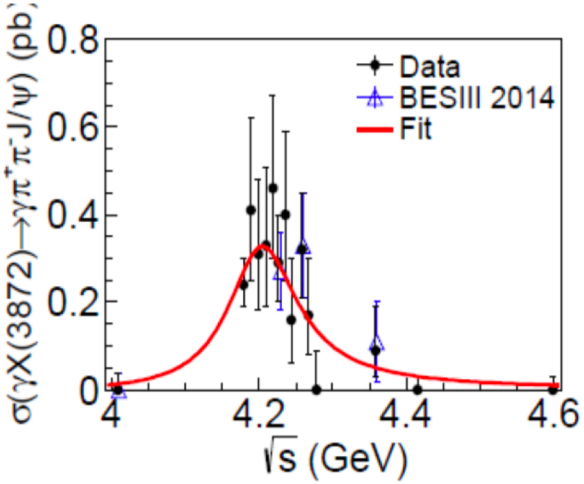


- Use 11.6/fb with $\sqrt{s}$=4.0~4.6 GeV.
- Observed $X(3915) \to \omega J/\psi$ with significance 3.1σ.
- $X(3915)$ mass: 3926.4± 2.2±1.2 MeV or 3932.6±8.7±4.7 MeV.
- $X(3915)$ width: 3.8±7.5±2.6 MeV or 59.7 ± 15.5± 3.7MeV.

$e^+e^- \to \gamma X(3872), X(3872) \to \omega J/\psi$

BESIII, PRL122, 232002 (2019)





$M = 4200.6^{+7.9}_{-13.3} \pm 3.0\ \mathrm{MeV/c^2}$

$\Gamma = 115^{+38}_{-26} \pm 12\ \mathrm{MeV}$

- Fitting cross section of $e^+e^- \to \gamma X(3872), X(3872) \to \omega J/\psi$ and $e^+e^- \to \gamma X(3872), X(3872) \to \pi^+\pi^- J/\psi$ to study Y(4220).

- $R=\frac{\mathcal{B}(X(3872)\to\omega J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}=1.6^{+0.4}_{-0.3} \pm 0.2$, roughly agree with BaBar measurements.

Study of $X(3872) \to \gamma J/\psi, \gamma\psi(3686)$

Requirement:

$cos\theta_\gamma \in [-0.7,\ 0.7]$ in $J/\psi \to e^+e^-$

$|M(\gamma_L\gamma_H) - m_{\pi^0(\eta)}| > 0.02(0.03)\ \mathrm{GeV/c^2}$

$|M(\gamma_L J/\psi) - m_{\chi_{c1,2}}| > 0.02\ \mathrm{GeV/c^2}$

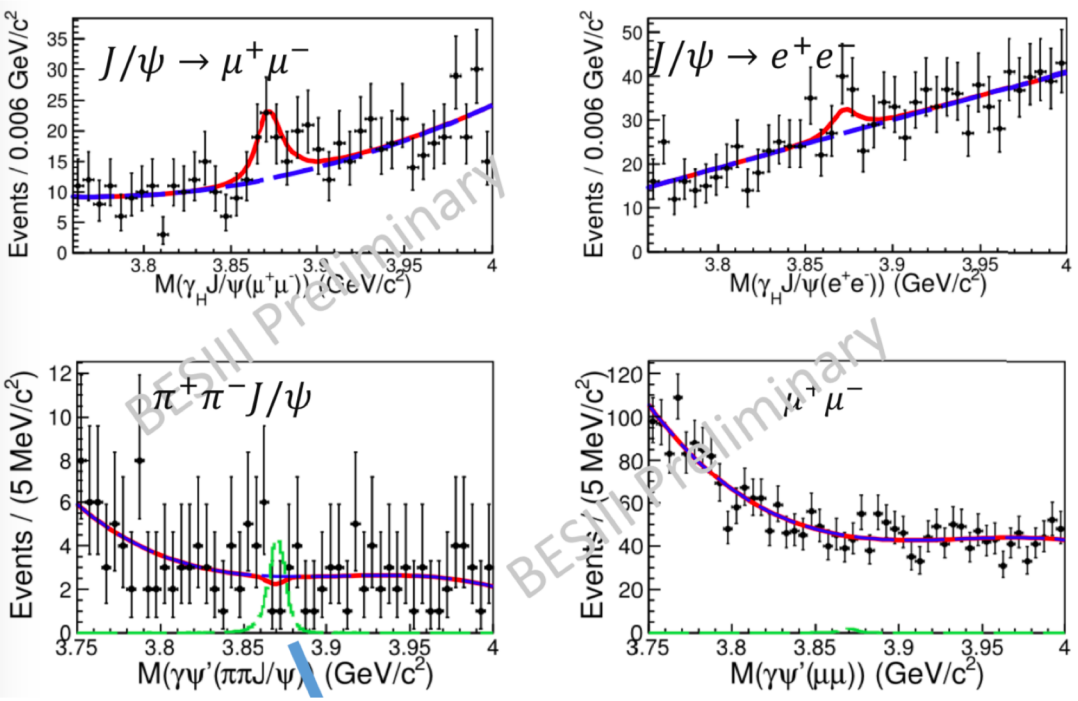
Simultaneous fit; significance $> 3.5\sigma$

Requirement:

$|M(\gamma_L\gamma_H) - m_{\pi^0(\eta)}| > 0.02(0.03)\ \mathrm{GeV/c^2}$

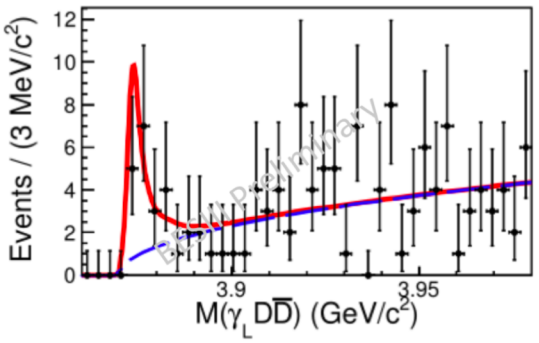
$|M(\pi^+\pi^-)_{recoil} - m_{\psi(3686)}| > 0.01\ \mathrm{GeV/c^2}$

Simultaneous fit; no evident signal

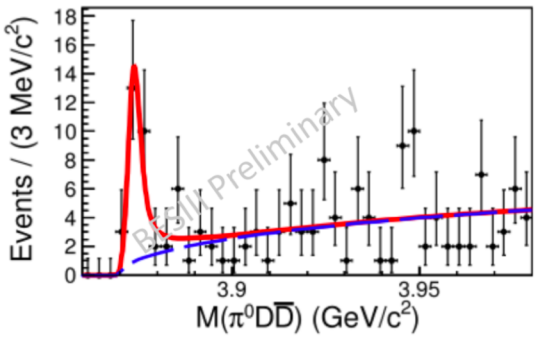


- $R=\frac{\mathcal{B}(X(3872)\to\gamma\psi(3686)}{\mathcal{B}(X(3872)\to\gamma J/\psi)}$<0.59 at 90% C.L. , agree with LHCb measurements.

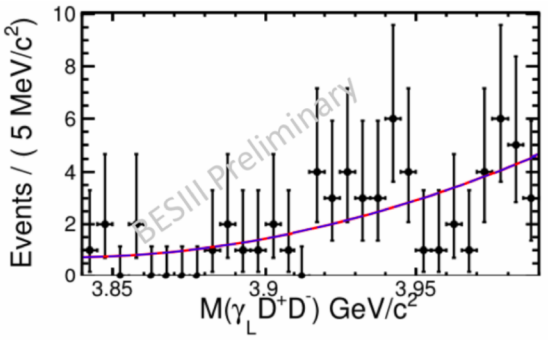
Study of $X(3872) \to D^0\bar{D}^{*0}$ and γD^+D^-



$N_{DD^*} = (25.5 \pm 4.4)$



$N_{DD^*} = (32.5 \pm 5.5)$



$N_{\gamma D^+D^-} = 0.0^{+0.5}_{-0.0}$

- Simultaneous fit on $D^{*0} \to \gamma D^0$ and $\pi^0 D^0$
- Significance $> 7.4\sigma$

No evident signal for γD^+D^-

mode	$D^{*0}\bar{D}^0 + c.c.$	$\gamma J/\psi$	$\gamma\psi'$	γD^+D^-	$\omega J/\psi$	$\pi^0\chi_{c1}$
ratio	14.81 ± 3.80	0.79 ± 0.28	< 0.42	< 0.99	$1.7^{+0.4}_{-0.3} \pm 0.2$ [27]	$0.88^{+0.33}_{-0.27} \pm 0.10$ [37]

arXiv:1903.04695 arXiv:1901.03992

Using the same way in Ref.[PRL **112**, 092001(2014)] to reconstruct $X(3872) \to \pi^+\pi^- J/\psi$ as the reference channel.

Absolute branching fraction of X(3872)

Index (i)	Parameters	Values	Experiments
	$X(3872) \to \pi^+\pi^- J/\psi$	($\times 10^{-6}$)	
1	$B^+ \to X(3872)K^+$	$8.61 \pm 0.82 \pm 0.52$	Belle [10]
2		$8.4 \pm 1.5 \pm 0.7$	BaBar [11]
3	$B^0 \to X(3872)K^0$	$4.3 \pm 1.2 \pm 0.4$	Belle [10]
4		$3.5 \pm 1.9 \pm 0.4$	BaBar [11]
	$X(3872) \to \gamma J/\psi$	($\times 10^{-6}$)	
5	$B^+ \to X(3872)K^+$	$1.78^{+0.48}_{-0.44} \pm 0.12$	Belle [18]
6		$2.8 \pm 0.8 \pm 0.1$	BaBar [19]
7	$B^0 \to X(3872)K^0$	$1.24^{+0.76}_{-0.61} \pm 0.11$	Belle [18]
8		$2.6 \pm 1.8 \pm 0.2$	BaBar [19]
	$X(3872) \to \gamma\psi(3686)$	($\times 10^{-6}$)	
9	$B^+ \to X(3872)K^+$	$0.83^{+1.98}_{-1.83} \pm 0.44$	Belle [18]
10		$9.5 \pm 2.7 \pm 0.6$	BaBar [19]
11	$B^0 \to X(3872)K^0$	$1.12^{+3.57}_{-2.90} \pm 0.57$	Belle [18]
12		$11.4 \pm 5.5 \pm 1.0$	BaBar [19]
	$X(3872) \to D^{*0}\bar{D}^0 + c.c.$	($\times 10^{-4}$)	
13	$B^+ \to X(3872)K^+$	$0.77 \pm 0.16 \pm 0.10$	Belle [12]
14		$1.67 \pm 0.36 \pm 0.47$	BaBar [13]
15	$B^0 \to X(3872)K^0$	$0.97 \pm 0.46 \pm 0.13$	Belle [12]
16		$2.22 \pm 1.05 \pm 0.42$	BaBar [13]
	$X(3872) \to \omega J/\psi$	($\times 10^{-6}$)	
17	$B^+ \to X(3872)K^+$	$6 \pm 2 \pm 1$	BaBar [14]
18	$B^0 \to X(3872)K^0$	$6 \pm 3 \pm 1$	BaBar [14]
	Ratios		
19	$\frac{\mathcal{B}(X(3872)\to\gamma J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	0.79 ± 0.28	BESIII [15]
20	$\frac{\mathcal{B}(X(3872)\to D^{*0}\bar{D}^0+c.c.)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	14.81 ± 3.80	BESIII [15]
21	$\frac{\mathcal{B}(X(3872)\to\omega J/\psi)}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	$1.6^{+0.4}_{-0.3} \pm 0.2$	BESIII [16]
22	$\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c1})}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)}$	$0.88^{+0.33}_{-0.27} \pm 0.10$	BESIII [17]
23	$\frac{\mathcal{B}(X(3872)\to\gamma\psi(3686))}{\mathcal{B}(X(3872)\to\gamma J/\psi)}$	$2.46 \pm 0.64 \pm 0.29$	LHCb [20]
	$B^+ \to X(3872)K^+$	($\times 10^{-4}$)	
24		$2.1 \pm 0.6 \pm 0.3$	BaBar [23]
25		$1.2 \pm 1.1 \pm 0.1$	Belle [22]

arXiv: 1907.09149

Parameter index	Decay mode	Branching fraction
1	$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \to D^{*0}\bar{D}^0 + c.c.$	$(52.4^{+25.3}_{-14.3})\%$
3	$X(3872) \to \gamma J/\psi$	$(1.1^{+0.6}_{-0.3})\%$
4	$X(3872) \to \gamma\psi(3686)$	$(2.4^{+1.3}_{-0.8})\%$
5	$X(3872) \to \pi^0\chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$
6	$X(3872) \to \omega J/\psi$	$(4.4^{+2.3}_{-1.3})\%$
7	$B^+ \to X(3872)B^+$	$(1.9 \pm 0.6) \times 10^{-4}$
8	$B^0 \to X(3872)K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
	$X(3872) \to$ unknown	$(31.9^{+18.1}_{-31.5})\%$

TABLE III: Correlation coefficients of the fit parameters listed in Table II.

Parameter index	1	2	3	4	5	6	7	8
1	1	0.87	0.84	0.75	0.64	0.79	-0.95	-0.87
2		1	0.79	0.71	0.56	0.74	-0.90	-0.77
3			1	0.78	0.54	0.73	-0.88	-0.78
4				1	0.49	0.65	-0.79	-0.69
5					1	0.51	-0.61	-0.56
6						1	-0.82	-0.72
7							1	0.84

- Neglect systematic correlation.
- Open charm decay is dominate.
- Large room for searching new decay modes.

Summary

- **Lots of progress in the study charmonium like states at BESIII.**
- **Many cross section lineshapes are measured.**
- **Y(4260)->Y(4220), seen in many final states.**
- **BESIII provide essential test for the existing X measurements.**
- **More analysis results on Zc states are in progress.**

Thanks