XYZ states: window to subatomic structure

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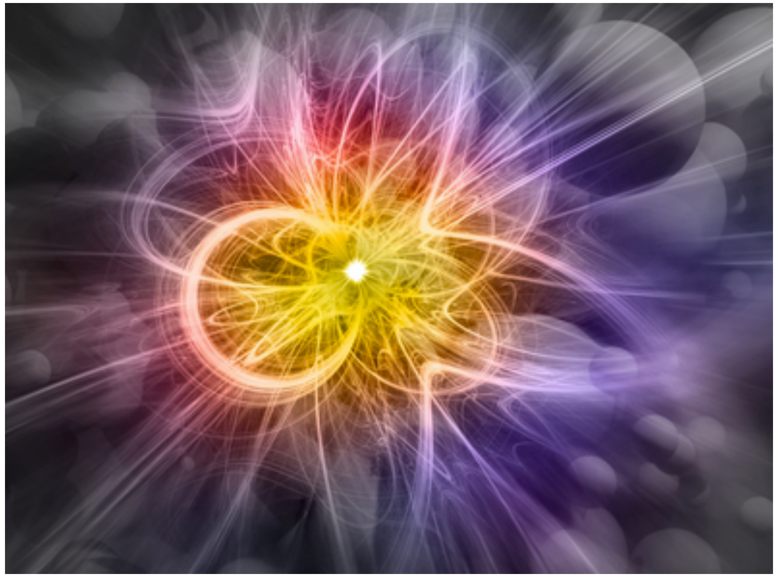
IHEP

Sep. 11, 2020

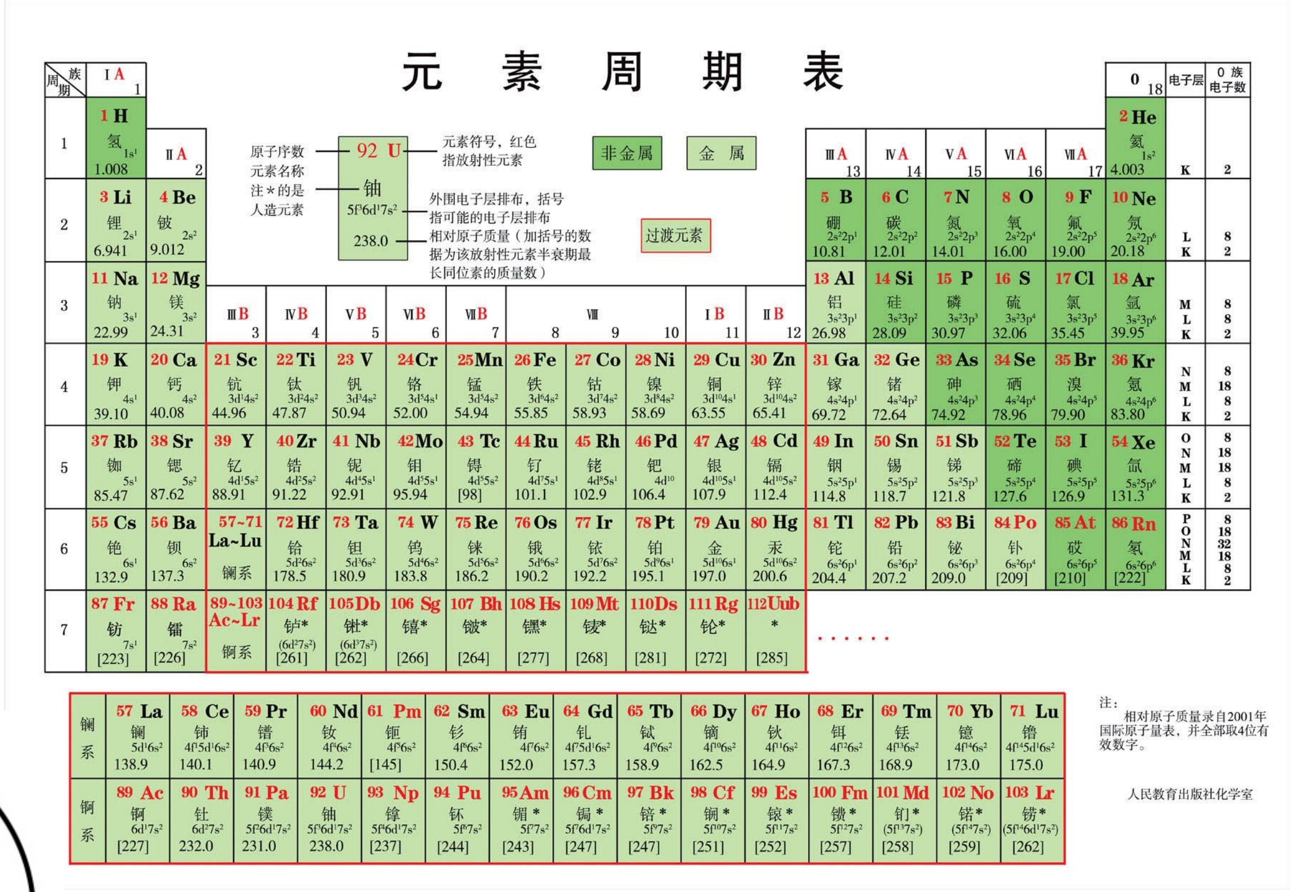
Frontier of human knowledge

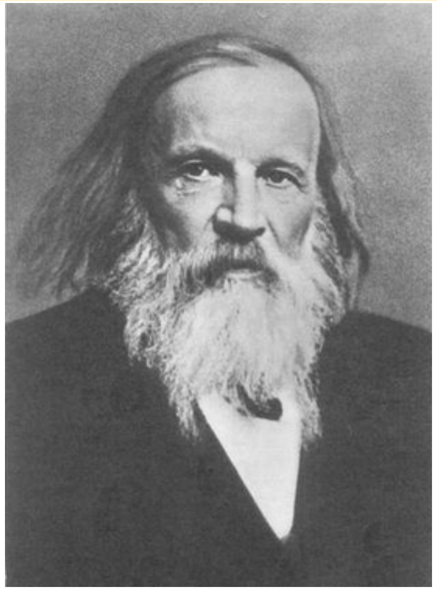


Micro-scale: What are we composed of?
Whether matter is infinitely dividable?

Cosmic scale: Where are we from?
Where to go?

Well accommodated Atoms



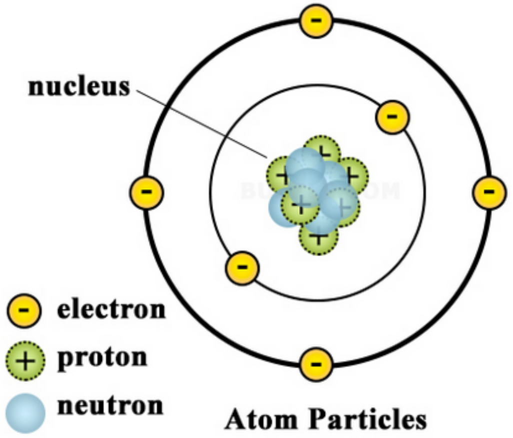


门捷列夫

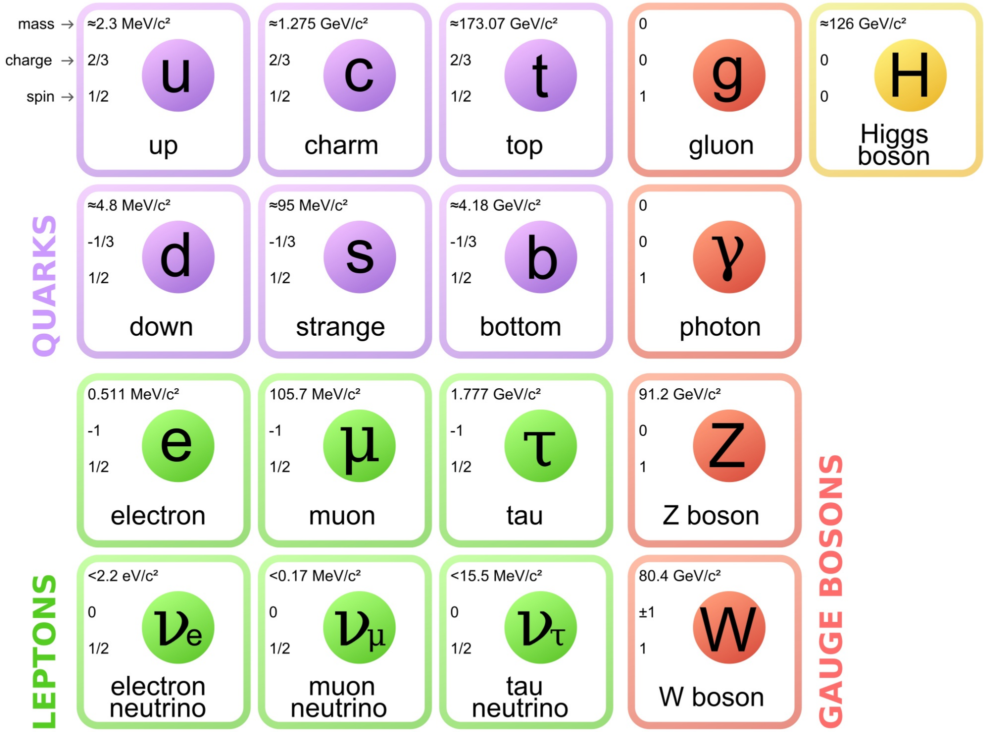
Dmitri Ivanovich Mendeleev

Дми́трий Ива́нович Менделе́ев

1834-1907



Quark model



Murray Gell-Mann
1929-2019

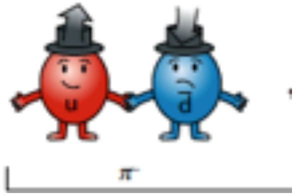
'quark'

George Zweig
1937-

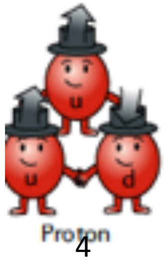
'Ace'

1964
u,d, s quarks
Proposed, SU(3)

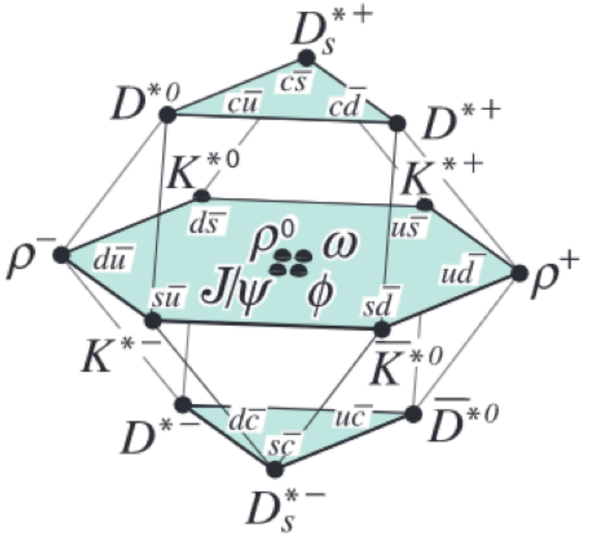
Meson:
Integer Spin
two quarks



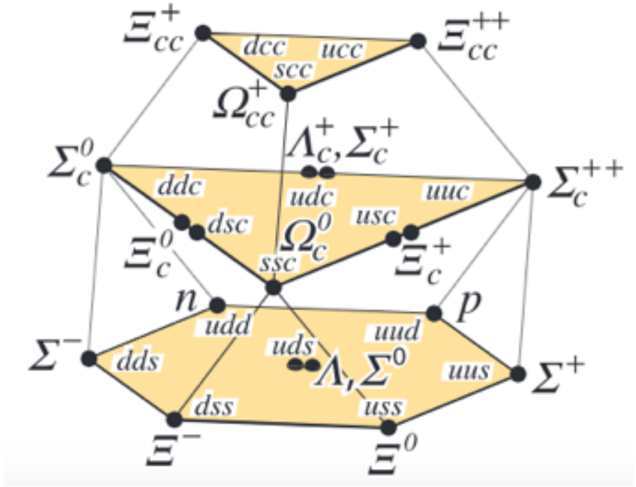
Baryon:
Half Integer Spin
Three quarks



Discovery of c quark



SU(3) Octet of Vector →SU(4) 16-plet



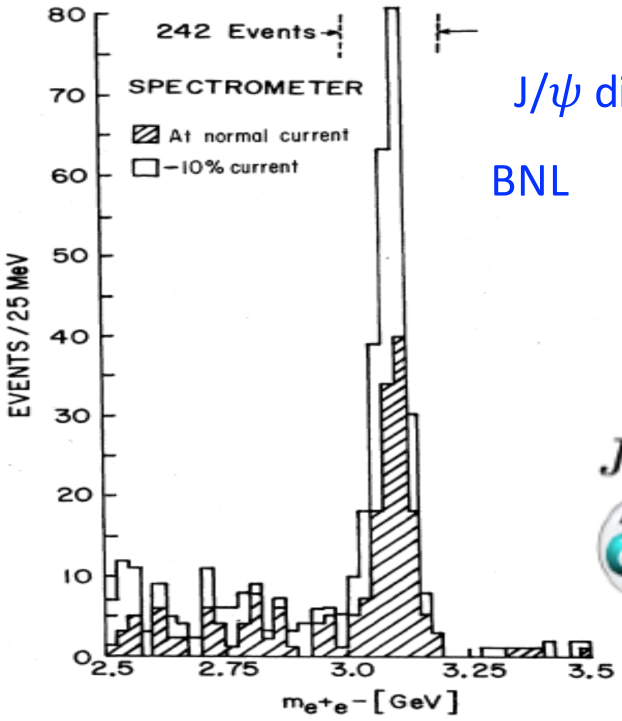
SU(3) Octet of hadron→ SU(4) 20-plet

丁肇中(Samuel Ting)

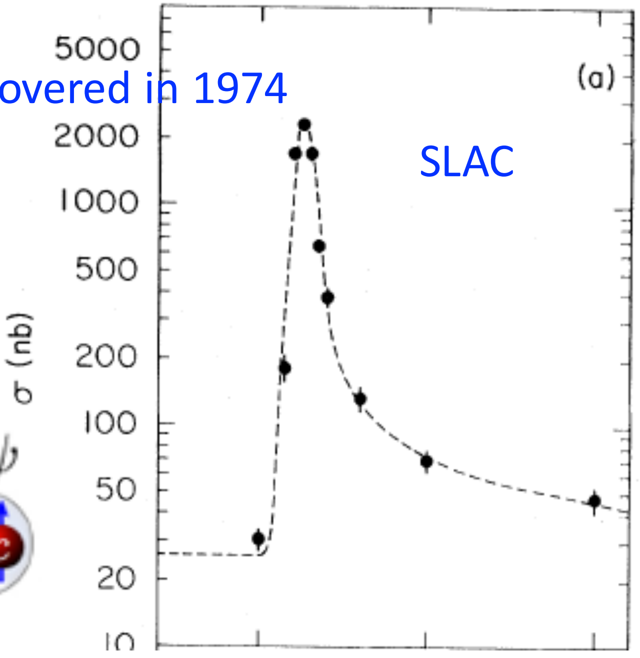
Burton Richter

J/ψ discovered in 1974

BNL



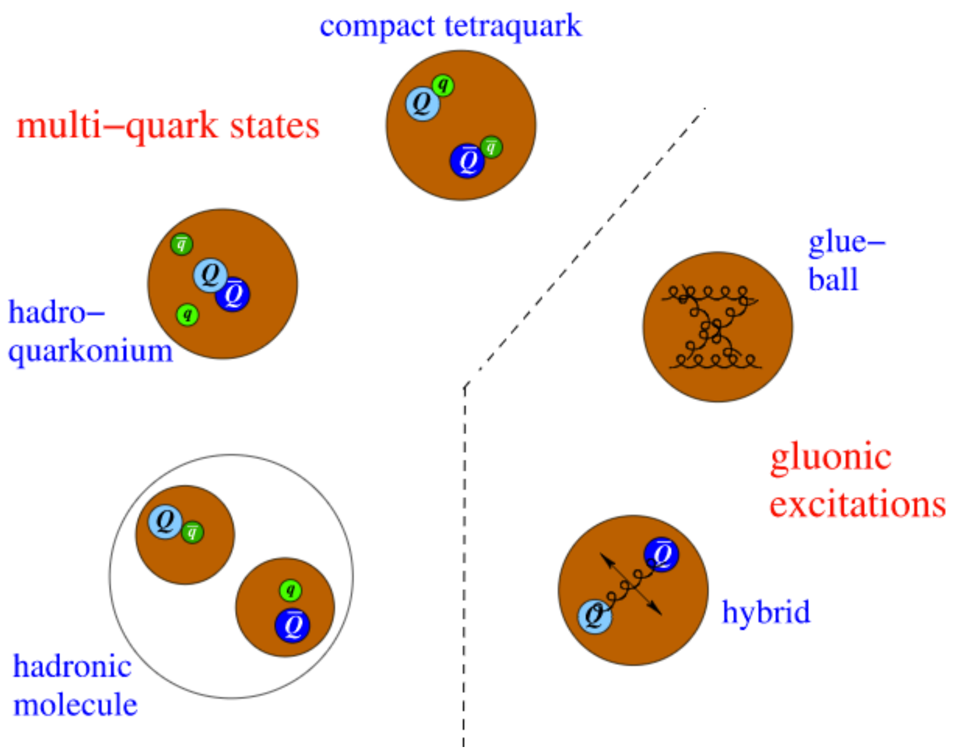
SLAC

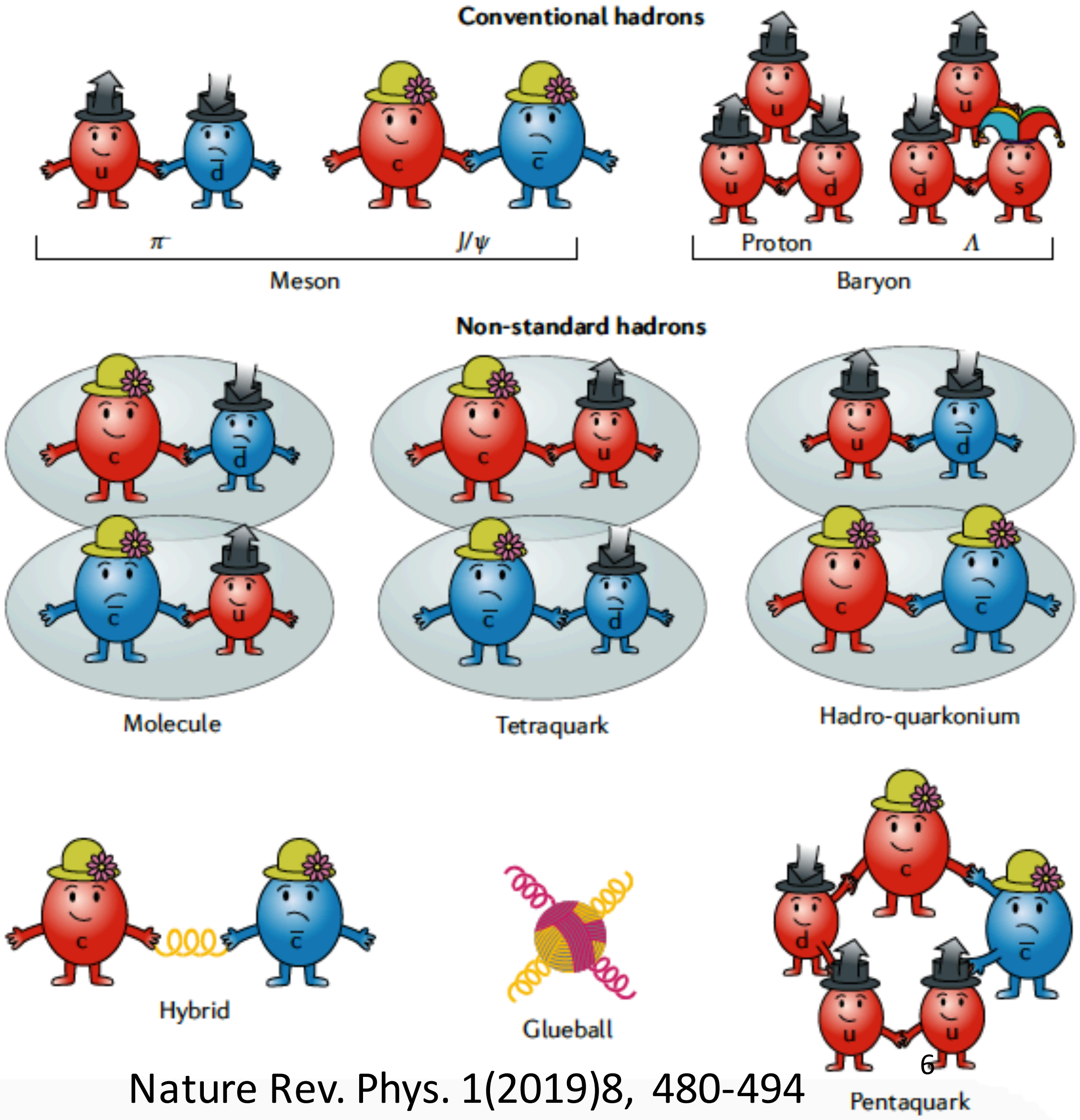


exotic states - XYZ states

- The exotic states: Molecule, Tetraquark, Hadro-quarkonium, Glueball, Hybrid, Penta-Quark
- Here are two pics from two papers

N. Brambilla, S. Eidelman, C. Hanhart et al. / Physics Reports 873 (2020) 1–154





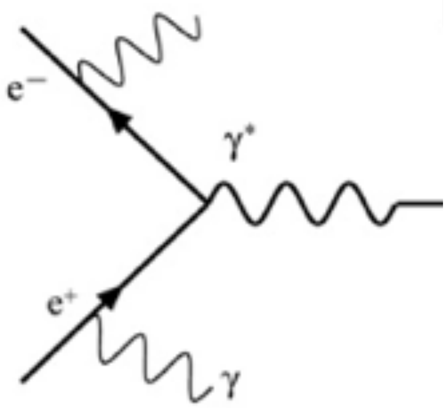
Nature Rev. Phys. 1(2019)8, 480-494

Part I: Y states

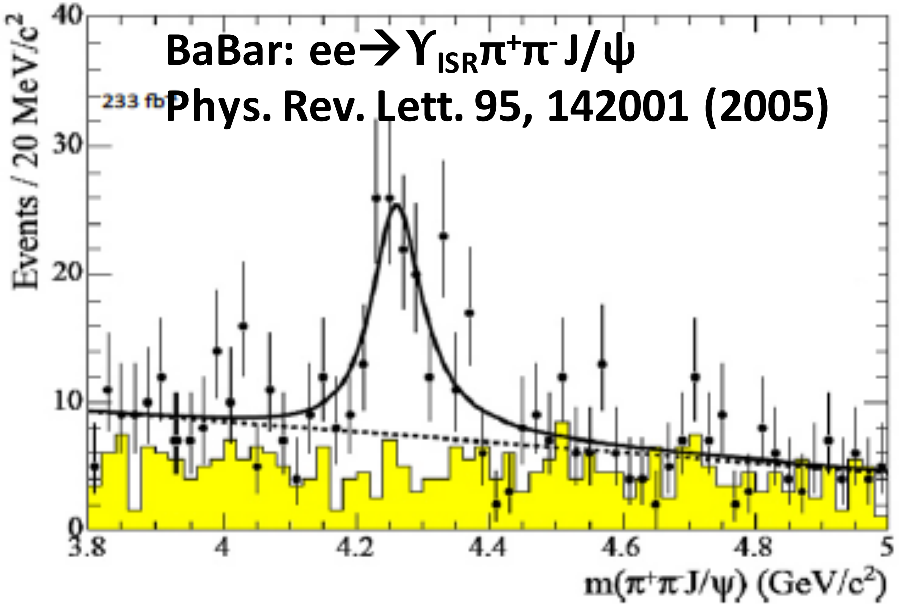
e^+e^- → ψ(1^{--}) (well established charmonium) → …

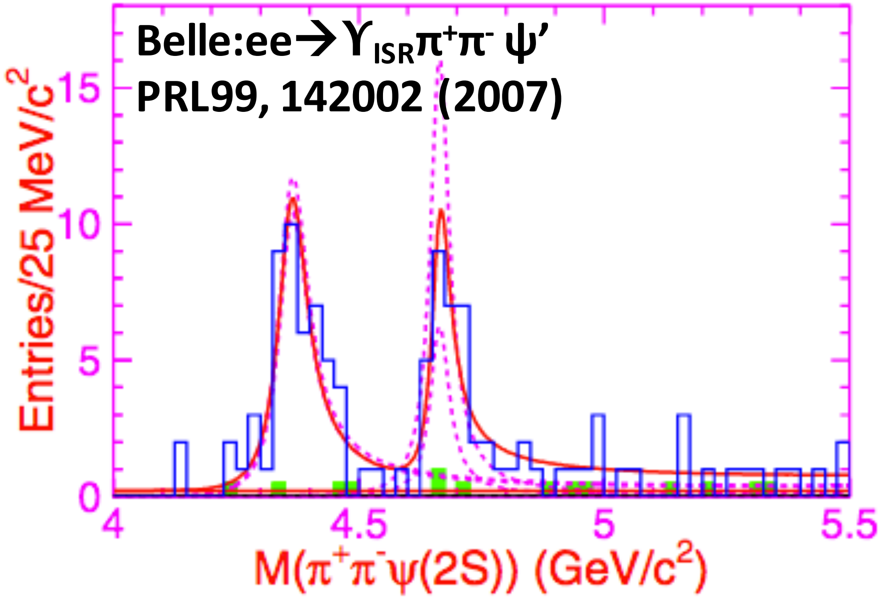
or

e^+e^- → Y(1^{--}) (Charmonium like, maybe exotic) → …



Y(4260),Y(4360) : some history





Y(4260) PDG value without BES result:
Mass= 4251±9 MeV
width= 120±12 MeV

Y(4360) PDG value without BES result:
mass= 4346±6 MeV
Width= 102±10 MeV

Y(4260) ~Y(4230)~Y(4220)

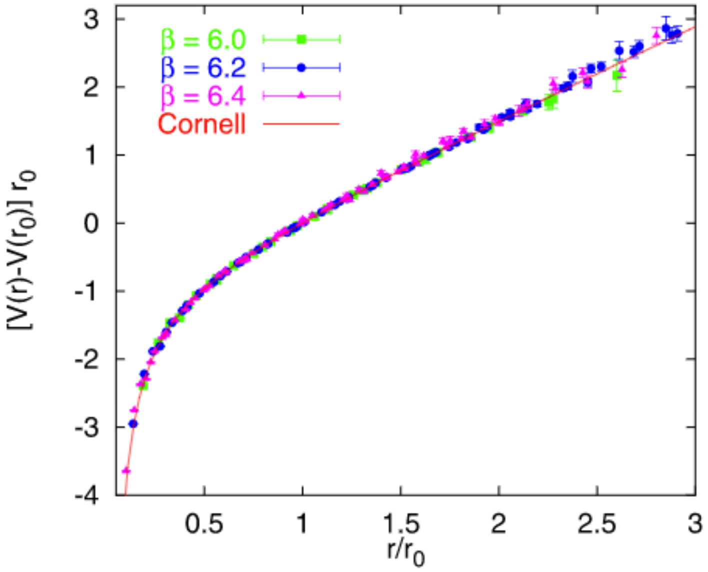
Why Y(4260) exotic?

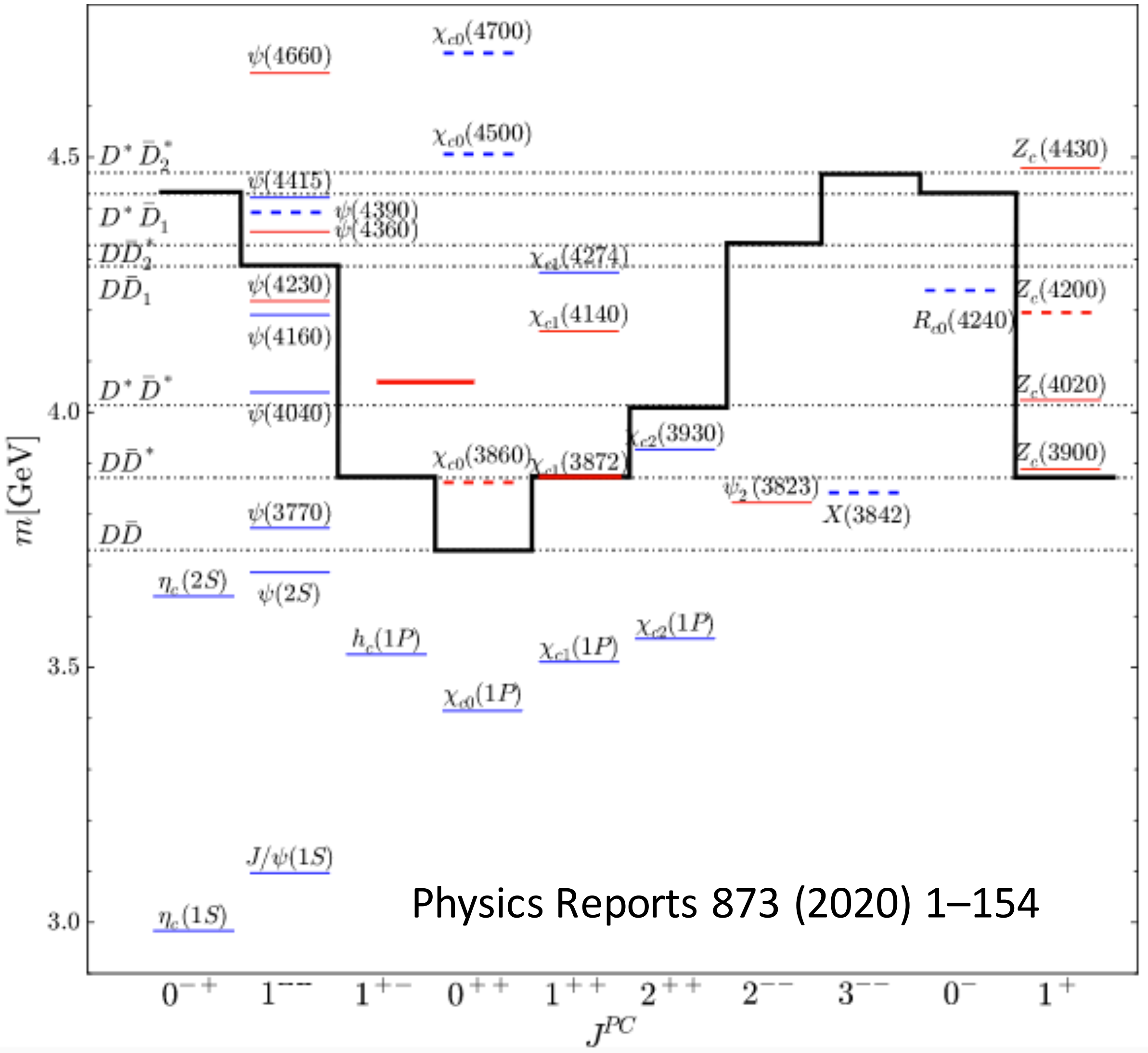
- Y(4260), Y(4360) don't have corresponding level with ($c\bar{c}$) potential model.

J/ψ(1S), ψ(3686)(2S), ψ(4040)(3S), ψ(4415)(4S).

ψ(3770)(1D), ψ(4160)(2D)

Cornell potential: $V^{(0)}(r) = -\frac{\kappa}{r} + \sigma r + C.$

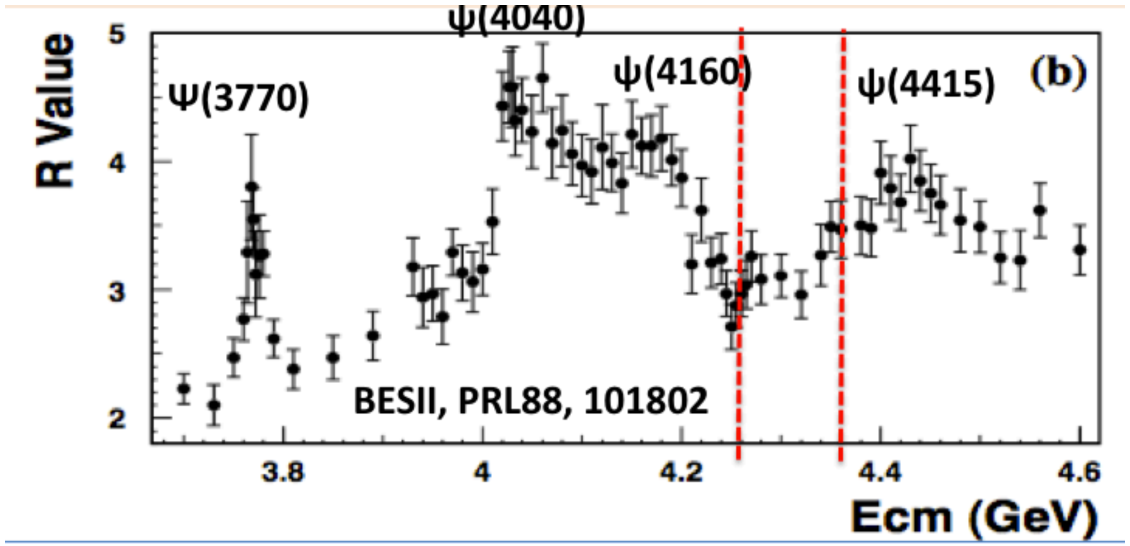




Physics Reports 873 (2020) 1–154

Why Y(4260) exotic?

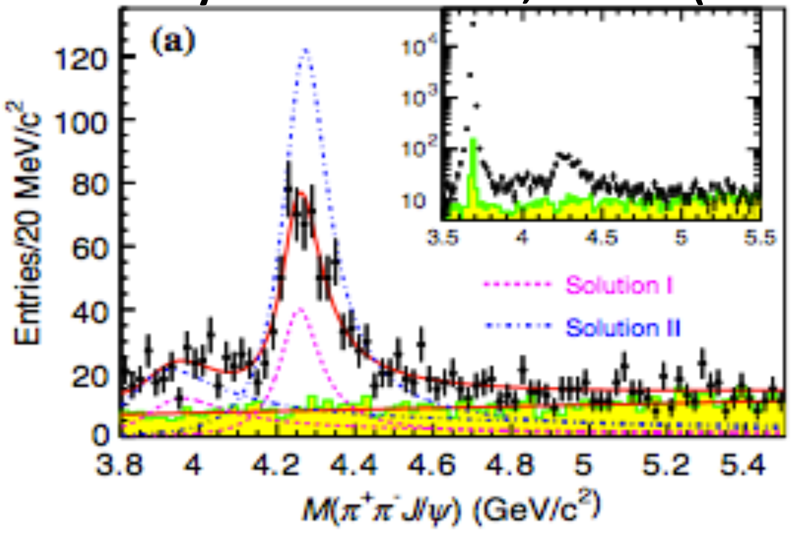
- Y(4260), Y(4360) doesn't correspond to a peak in R scan spectrum.



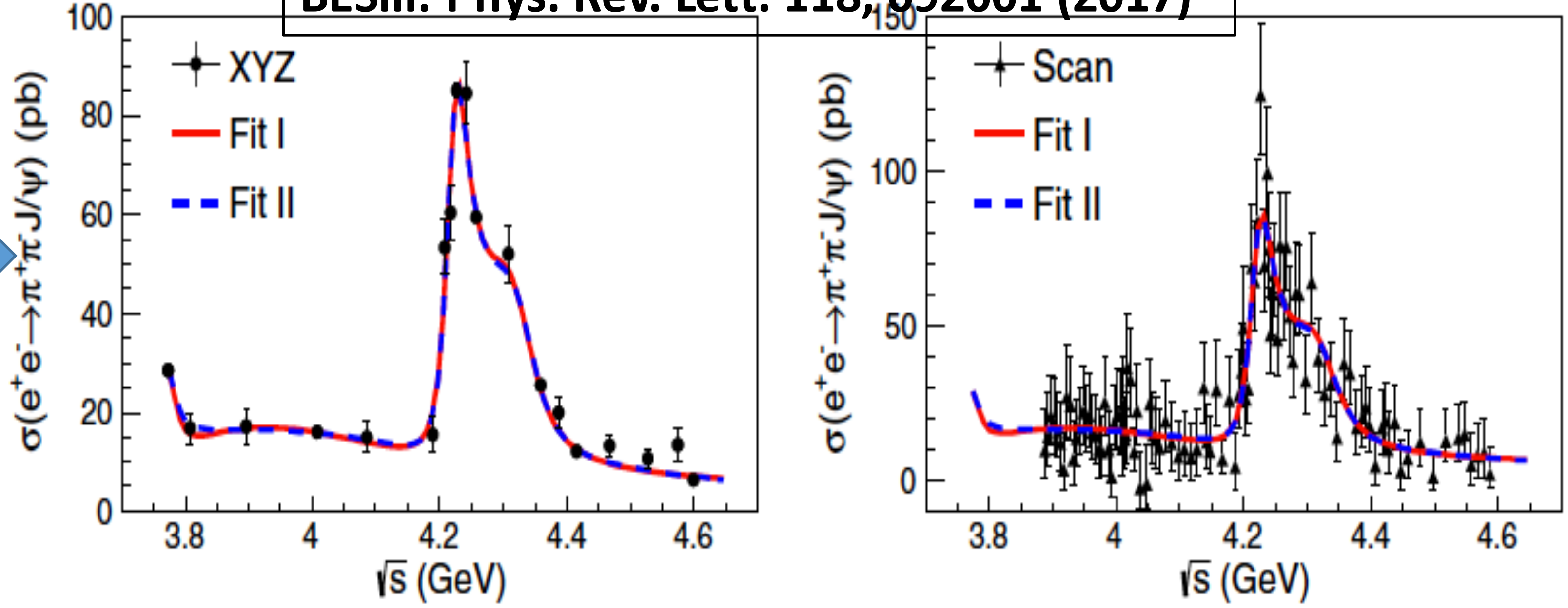
- Y(4260) has much smaller coupling to open charm compare with observed ψ states, which is not an expected behavior of charmonium in open charm range

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

Belle: ee→$\Upsilon_{ISR}\pi^+\pi^-$ J/ψ
Phys. Rev. Lett. 110, 252002(2013)



BESIII: Phys. Rev. Lett. 118, 092001 (2017)



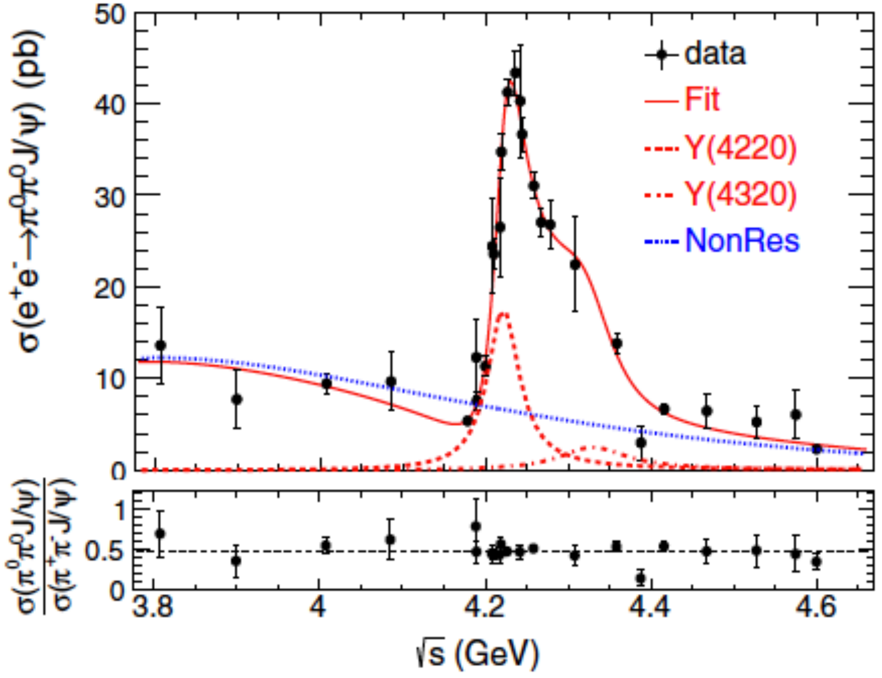
Y(4260):Mass=4251±9 MeV, width= 120±12 MeV → Y(4220):M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV

Y(4360):Mass=4346±6 MeV ,width 102±10 MeV → M = (4320.0±10.4±7) MeV, Γ = (101.4±25±10) MeV

3.86fb-1 at 8 energy points taken at 2017, and 3.9fb-1 at 8 energy points taken at 2019 can give more precise result.

Cross section of $e^+e^- \to \pi^0\pi^0 J/\psi$

PRD 102, 012009 (2020)

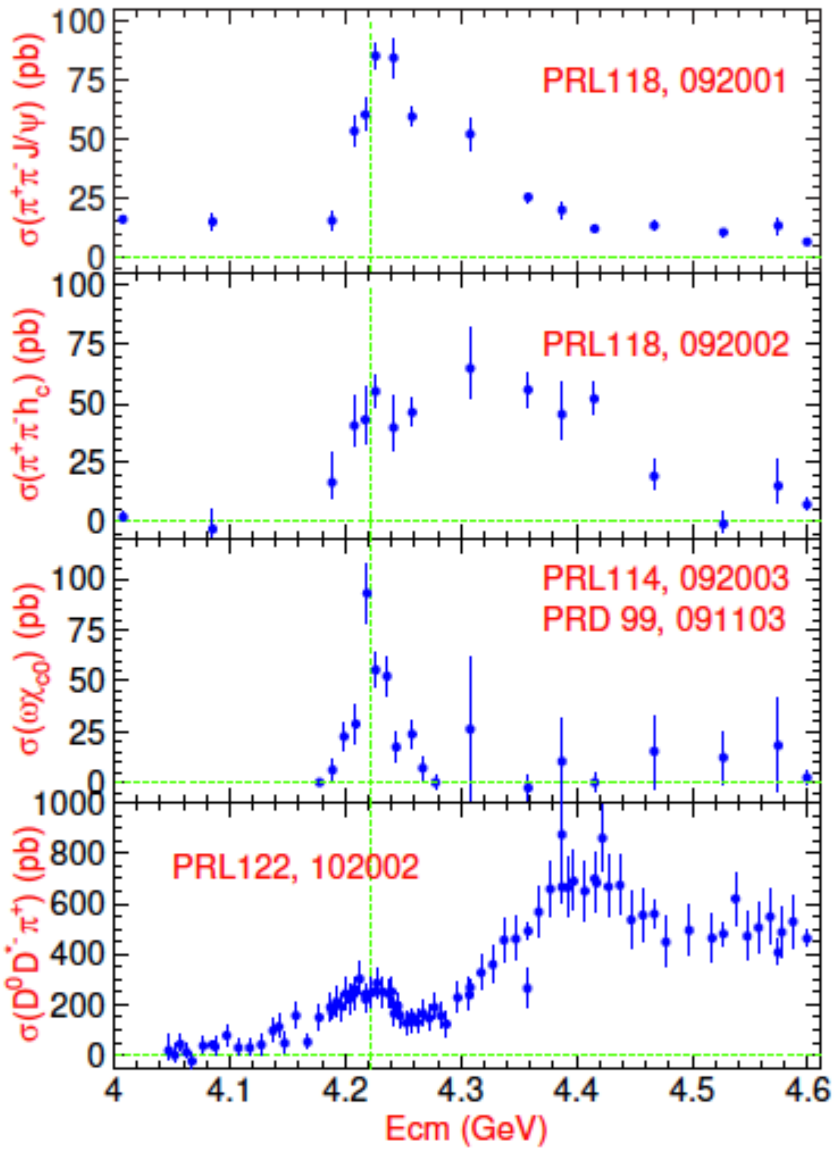


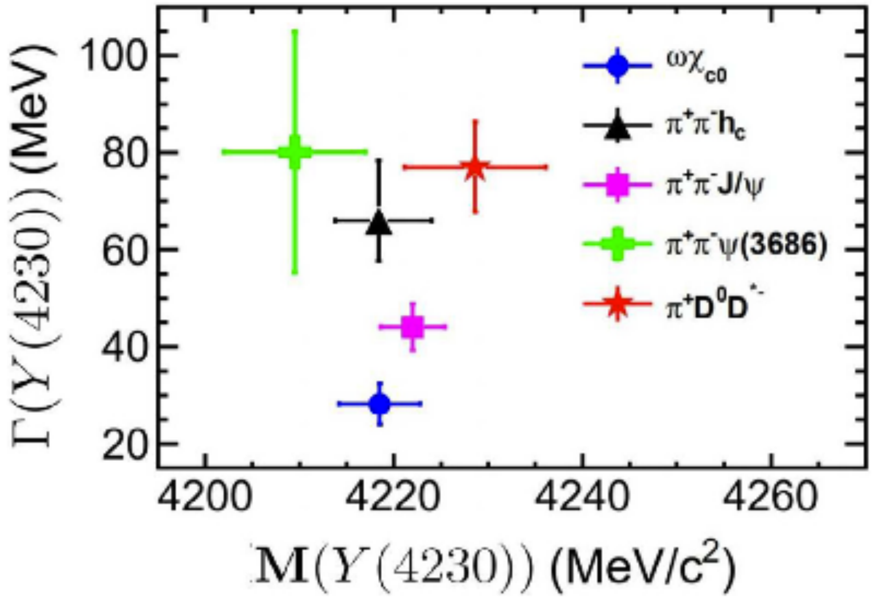
The measured cross section compared with $e^+e^- \to \pi^+\pi^- J/\psi$
Satisfy the isospin symmetry.

In the fitting, the parameter of Y(4320) are fixed.
And the measured parameter of Y(4220) also agree with that in $e^+e^- \to \pi^+\pi^- J/\psi$.

Y(4220):M = (4220.4 ± 2.4 ± 2.3) MeV, Γ = (46.2 ± 4.7 ± 2.1) MeV

Y(4230) in other channels





The mass of Y(4230) now is much smaller than the threshold of DD1(2420)~4285MeV, this reduce the probability (DD1(2420)) molecular description but can't rule it out.

Tetraquark mode
(qQ)($\bar{q}\bar{Q}$) = 4.244 GeV
(sQ)($\bar{s}\bar{Q}$) = 4.466 GeV

Coupled channels fit

arXiv:1805.03565

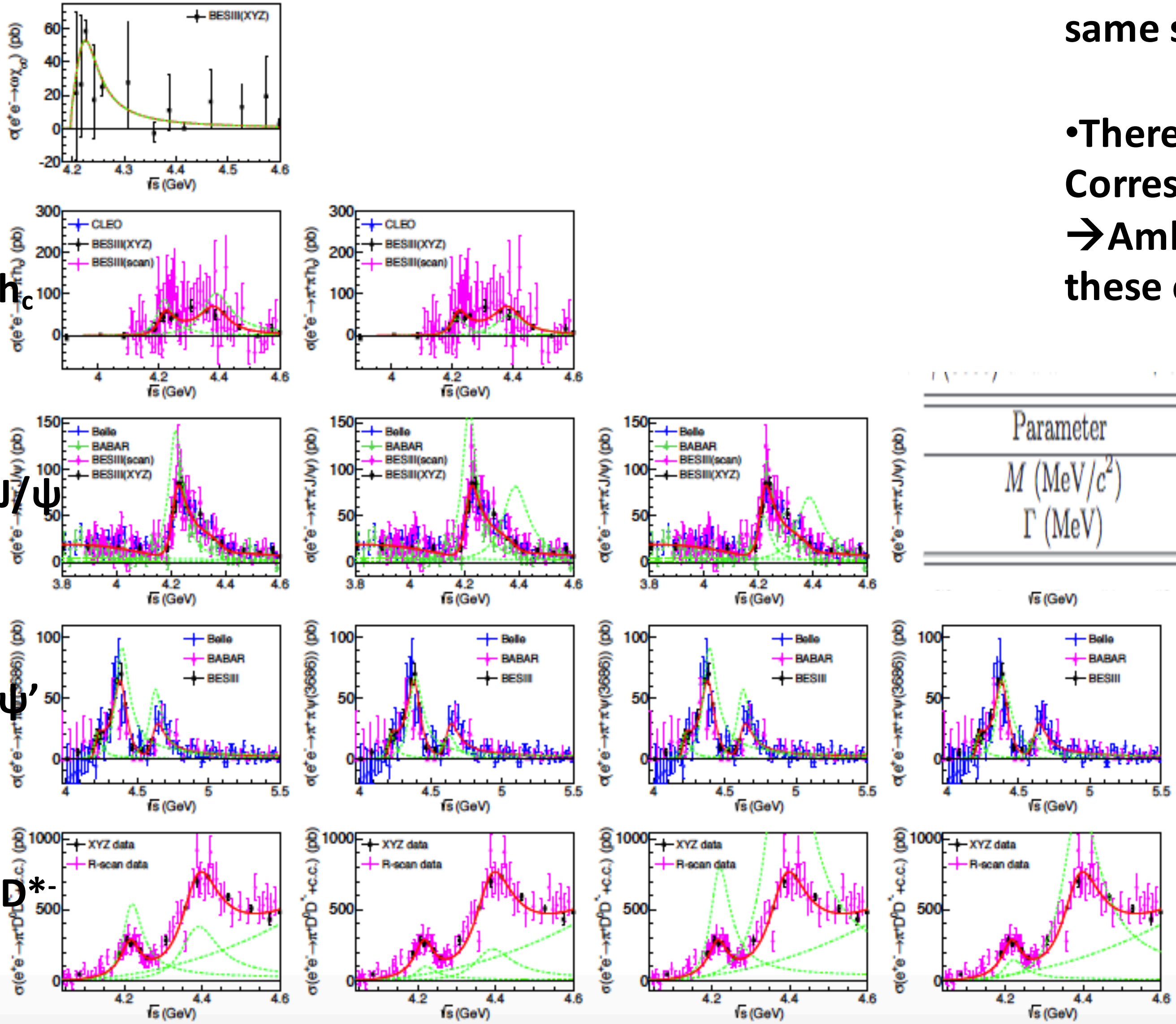
$e^+e^- \to \omega\chi_{cJ}$

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

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

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

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



- The fit give $\chi^2/ndf=0.97$, which indicate that the two same states assumption is reasonable.

- There are multi-solution problem. Each column Corresponding to one solution.
→Ambiguity in couple fraction between Y states and these channels.

Parameter	$Y(4220)$	$Y(4390)$	$Y(4660)$
M (MeV/c^2)	$4216.5 \pm 1.4 \pm 3.2$	$4383.5 \pm 1.9 \pm 6.0$	$4623.4 \pm 10.5 \pm 16.1$
Γ (MeV)	$61.1 \pm 2.3 \pm 3.1$	$114.5 \pm 5.4 \pm 9.9$	$106.1 \pm 16.2 \pm 17.5$

Extraction of Γ_{ee} of Y(4230)

- Γ_{ee} is the decay width of Y(4230) to e^+e^-.
- Different model predicted Γ_{ee}:

Hybrid: ~40eV (CPC40, 081002(2006))
DD1(2420) Molecule: ~500eV (PRD94, 054035(2016))

$4\ ^3S_1$ $c\bar{c}$ states: ~1KeV (PRD79,094004 (2009))
$3\ ^3D_1$ $c\bar{c}$ states: ~44eV

- In Arxiv:2002.05641, they performed a fit to all the Y(4230) decay channels

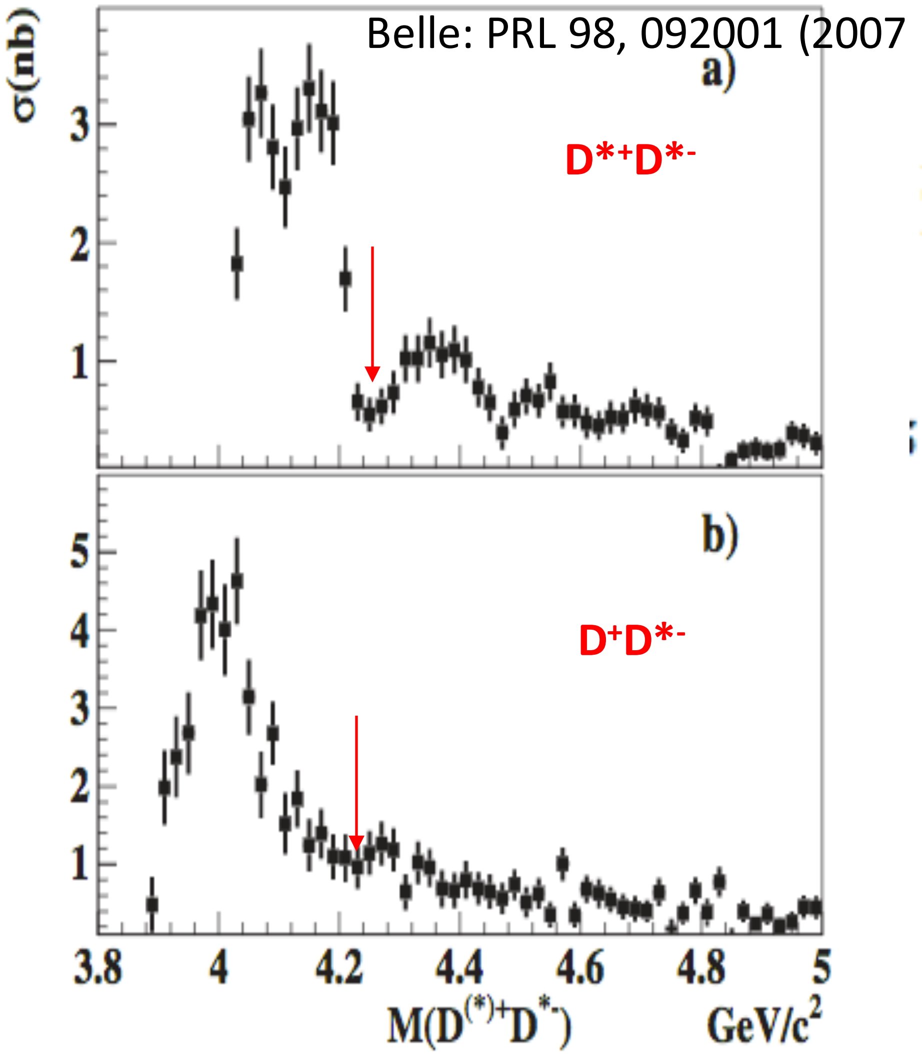
$$\Gamma_{tot}(s) = \Gamma_{J/\psi\pi\pi}(s) + \Gamma_{h_c\pi\pi}(s) + \Gamma_{D\bar{D}^*\pi}(s) + \Gamma_{\psi(2S)\pi\pi}(s) + \Gamma_{\omega\chi_{c0}} + \Gamma_{J/\psi\eta} + \Gamma_{D_s^*\bar{D}_s^*} + \Gamma_{D\bar{D}} + \Gamma_{D\bar{D}^*} + \Gamma_{D^*\bar{D}^*} + \Gamma_0.$$

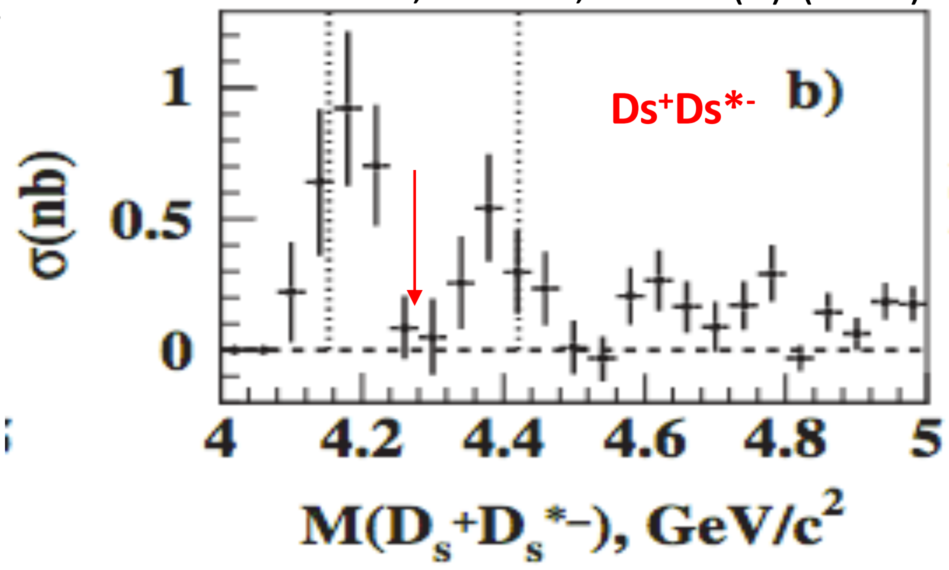
$$\Gamma_{e^+e^-} = \frac{4\alpha}{3}\frac{g_0^2}{M_X}.$$

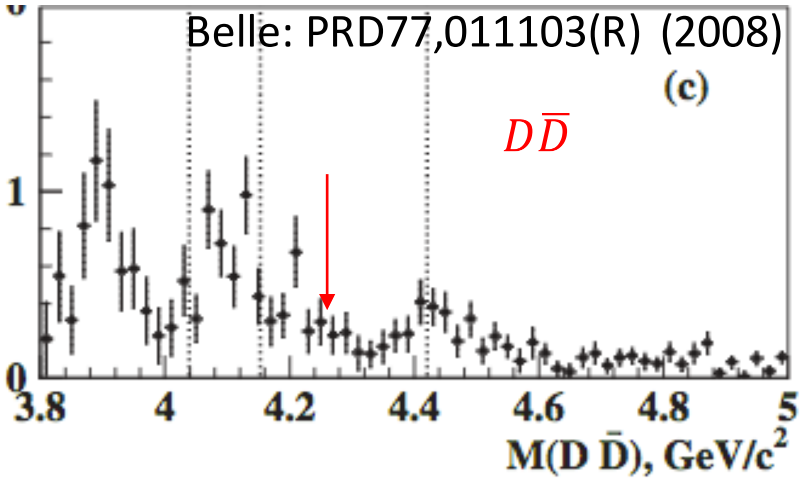
$$\sigma_{e^+e^-\to X(4260)\to f} = \frac{3\pi}{k^2}\left|\frac{\sqrt{s\Gamma_{ee}\Gamma_f}}{s - M_X^2 + i\sqrt{s}\Gamma_{tot}(s)} + \sum_i \frac{c_i e^{i\phi_i}}{s - M_i^2 + i\sqrt{s}\Gamma_i} + \tilde{c}\right|^2,$$

Result : Γ_{ee}=1.302KeV with Ds*Ds* , Γ_{ee}=0.466KeV without Ds*Ds*
Exclude the Hybrid or pure $^3D_1$ model

e^+e^- →open charm mesons



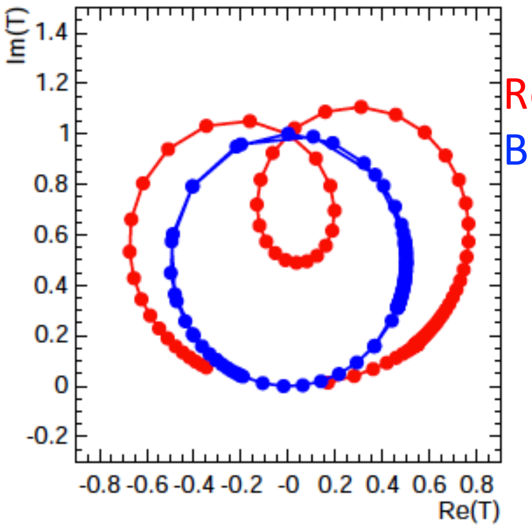


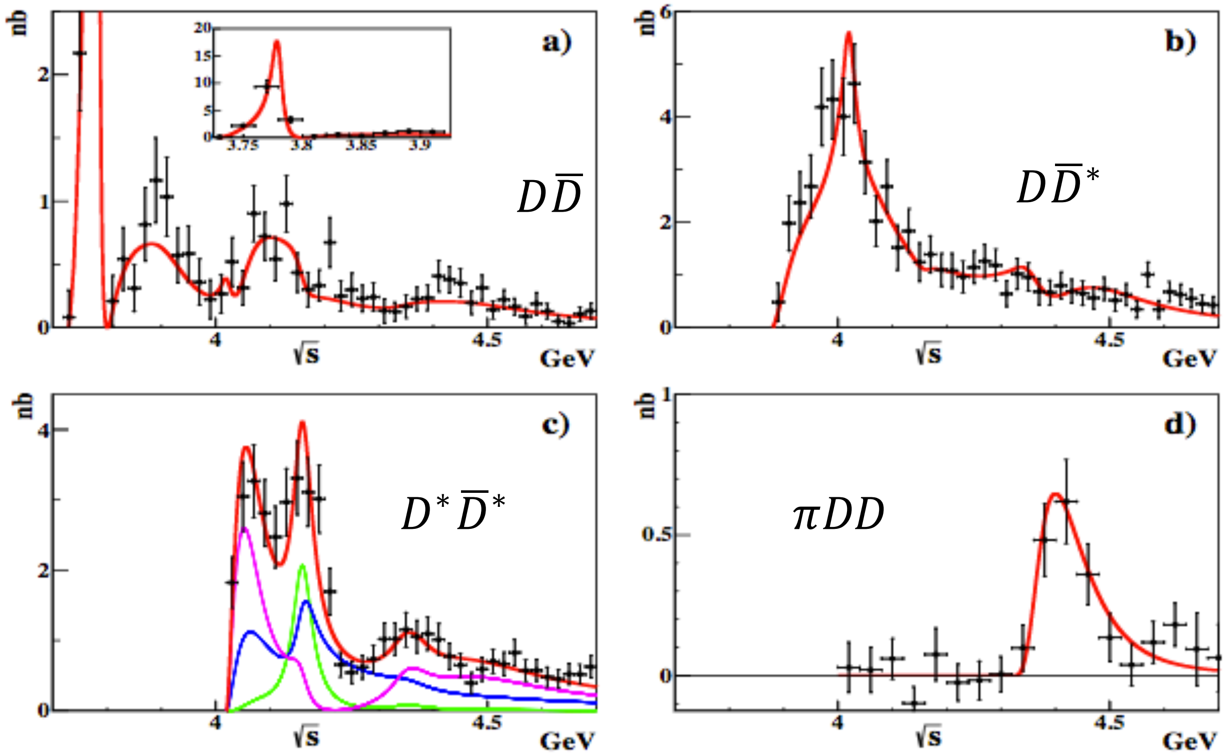


- Y(4230) has much smaller coupling to open charm compare with observed ψ states, which is not an expected behavior of charmonium states.

About the fitting-Unitarity

- Sum of Breit-Wigners doesn't satisfy the S-matrix's unitarity, while K-matrix does.





Timofey Uglov

arXiv:1611.07582v2

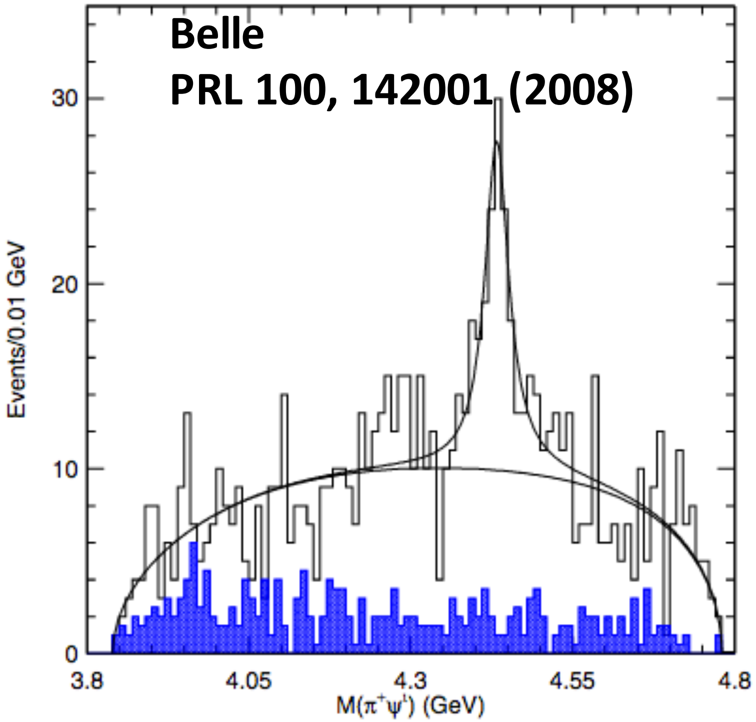
Fitting Belle's open charm result with K-matrix method

Fitted well with only ψ states

Part II: Zc states

Isospin non-zero charmonium like states

$Z_c(4430)^-$



- ☐ **The first Zc state is observed by Belle in B→K$\pi^-\psi$'**

M=4433$\pm 4 \pm 2$ MeV
Γ=45^{+18+30}_{-13-13} MeV

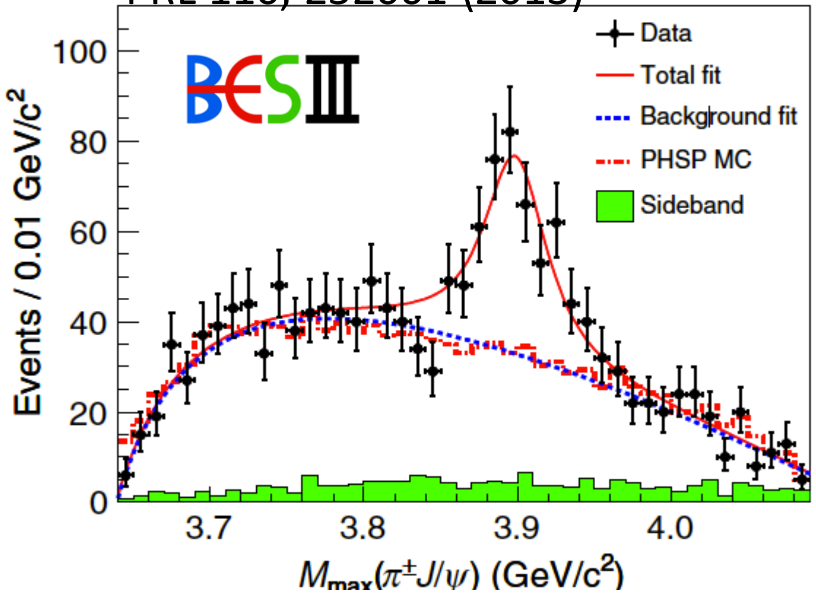
- ☐ **J^p prefer to be 1^+**

Other Zc states observed in B decay

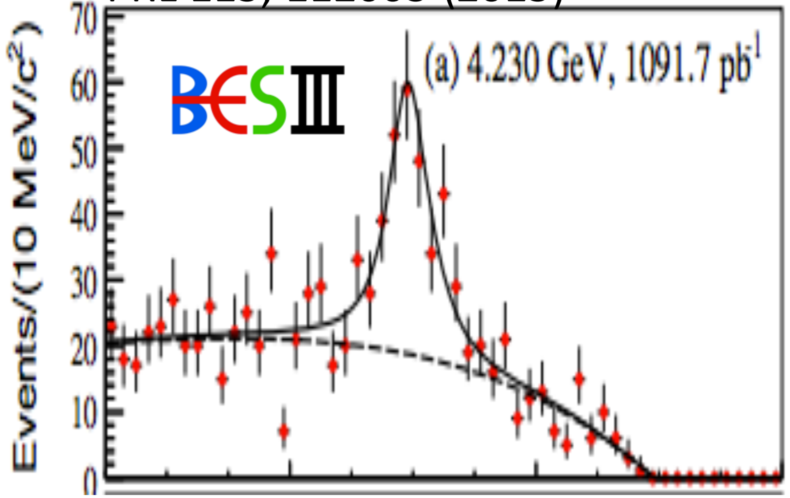
- ☐ **Zc(4050),Zc(4250) in B→K$\pi^-\chi_{c1}$, Belle, PRD 78 (2008) 072004**
- ☐ **Zc(4200) in B→K$\pi^- J/\psi$, Belle, PRD 90 (2014) 112009**

Zc(3900)$^{\pm,0}$ in $\pi^+\pi^-$ J/ψ, $\pi^0\pi^0$ J/ψ

PRL 110, 252001 (2013)



PRL 115, 112003 (2015)



•The mass of Zc(3900) is in opencharm range and strongly coupled to charm → it should contain a (ccbar) pair.
•Zc(3900)$^{\pm}$ is charged → need at least two more quarks to form a charge unit.

Z_c(3900) is a four quark states?

❑Tetraquark states?

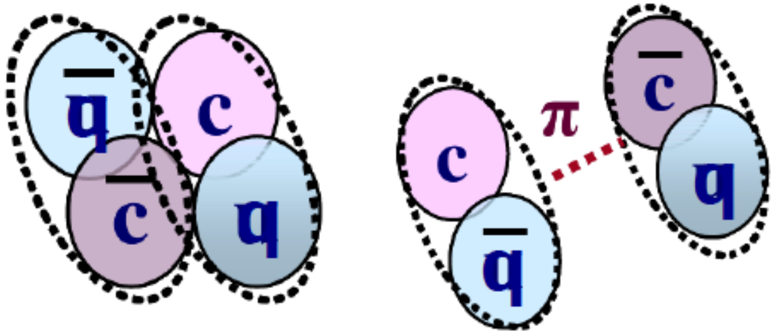
Phys. Rev. D89,054019(2014);

Phys. Rev. D90,054009(2014);

❑Zc(3900) is near the threshold of (DD*) → A molecular states?

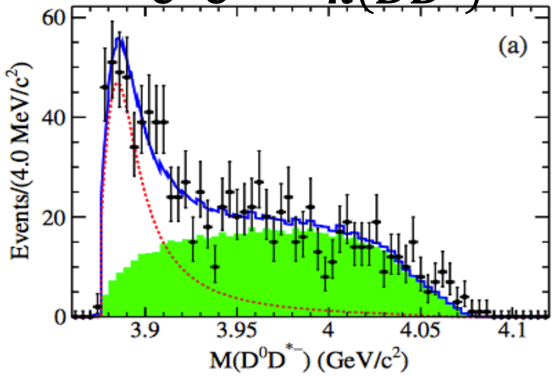
Arxiv:1303.6608, 1304.2882

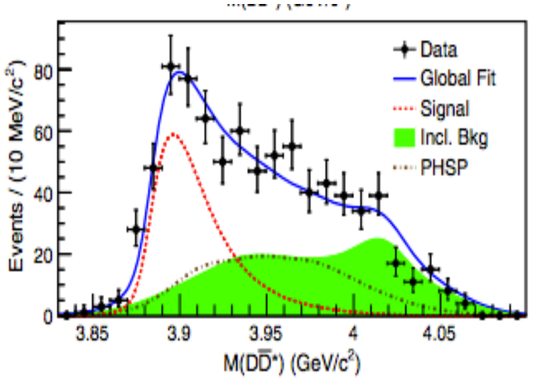
OR other explanation?



Zc(3900), Zc(4020)

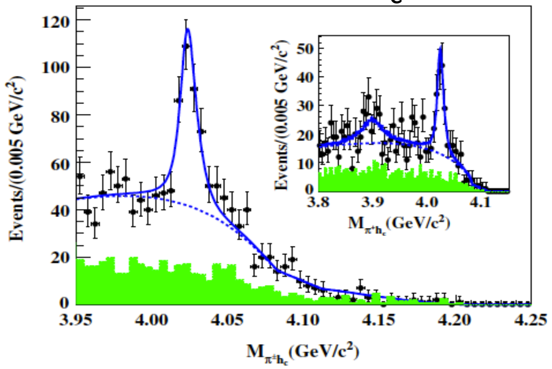
$e^+e^- \to \pi(D\bar{D}^*)$

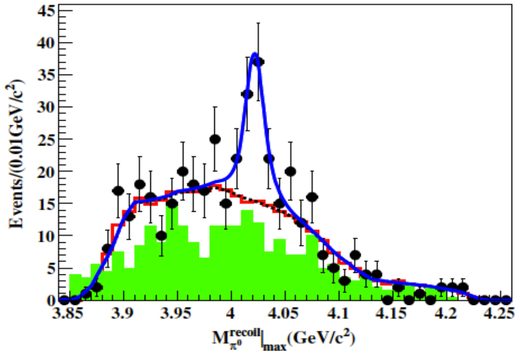




PRL 112, 022001 (2014)
PRD 92, 092006 (2015)
PRL115, 222002(2015)

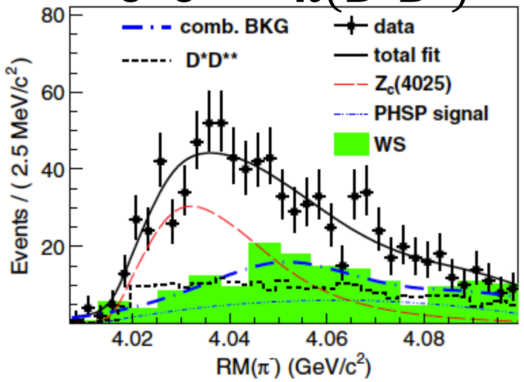
$e^+e^- \to \pi^+\pi^- h_c$

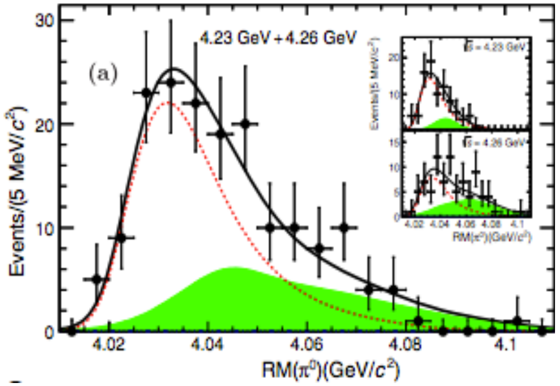




PRL 111, 242001 (2013)
PRL 113, 212002 (2014)

$e^+e^- \to \pi(D^*\bar{D}^*)$





PRL 112, 132001 (2014)
PRL 115, 182002 (2015)

$\Gamma(Z_c(3900) \rightarrow DD^*)/\Gamma(Z_c(3900) \rightarrow \pi J/\psi)$

- This ratio is important for discriminating the Zc model.
- Experiment result without interference considered

  $\Gamma(Zc \rightarrow DD^*)/\Gamma(Zc \rightarrow \pi J/\psi) = 6.2 \pm 2.7$

- Theoretical work, PRD94, 094017 (2016)

➢TetraQuark

$$\Gamma(Z_c^+ \to J/\psi + \pi^+) = (4.3^{+0.7}_{-0.6})\ \text{MeV},$$
$$\Gamma(Z_c^+ \to \eta_c + \rho^+) = (8.0^{+1.2}_{-1.0})\ \text{MeV},$$
$$\Gamma(Z_c^+ \to \bar{D}^0 + D^{*+}) \propto 10^{-9}\ \text{MeV},$$
$$\Gamma(Z_c^+ \to \bar{D}^{*0} + D^+) \propto 10^{-9}\ \text{MeV}.$$

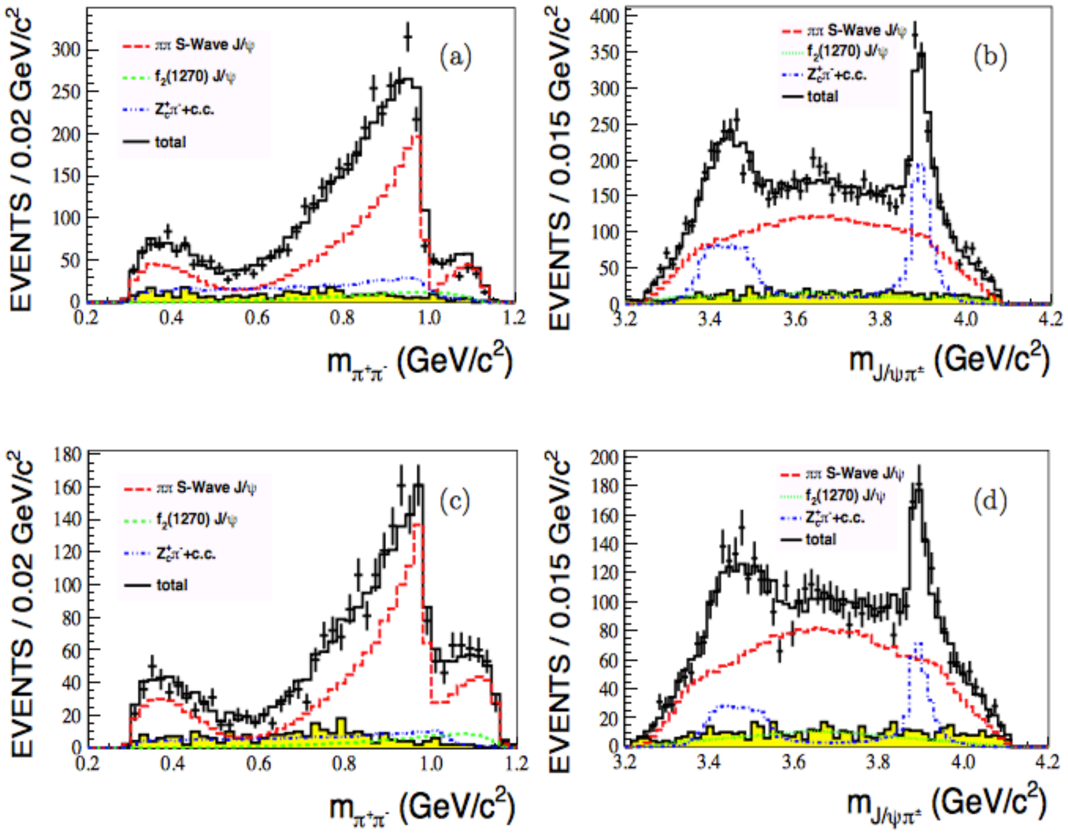
➢Molecule

$$\Gamma(Z_c^+ \to J/\psi + \pi^+) = (1.8 \pm 0.3)\ \text{MeV},$$
$$\Gamma(Z_c^+ \to \eta_c + \rho^+) = (3.2^{+0.5}_{-0.4})\ \text{MeV},$$
$$\Gamma(Z_c^+ \to \bar{D}^0 + D^{*+}) = (10.0^{+1.7}_{-1.4})\ \text{MeV},$$
$$\Gamma(Z_c^+ \to \bar{D}^{*0} + D^+) = (9.0^{+1.6}_{-1.3})\ \text{MeV}.$$

prefered

Determination of J^P of Zc(3900)

PRL 119, 072001 (2017)



√s=4.23GeV

√s=4.26GeV

- ❑PWA with helicity formalism taking $\pi^+\pi^- J/\psi$ as final states
- ❑Simultaneous fit to data samples at 4.23GeV and 4.26GeV
- ❑$\pi^+\pi^-$ spectrum is parameterized with σ, $f_0(980)$, $f_2(1270)$ and $f_0(1370)$

Determination of J^p of Zc(3900)

- **Zc is parameterized with Flatte formula**

$$BW(s, M, g_1', g_2') = \frac{1}{s - M^2 + i[g_1'\rho_1(s) + g_2'\rho_2(s)]}$$

- **M=(3901.5±2.7±38.0)MeV, g_1'=(0.075±0.006±0.025)GeV^2,**

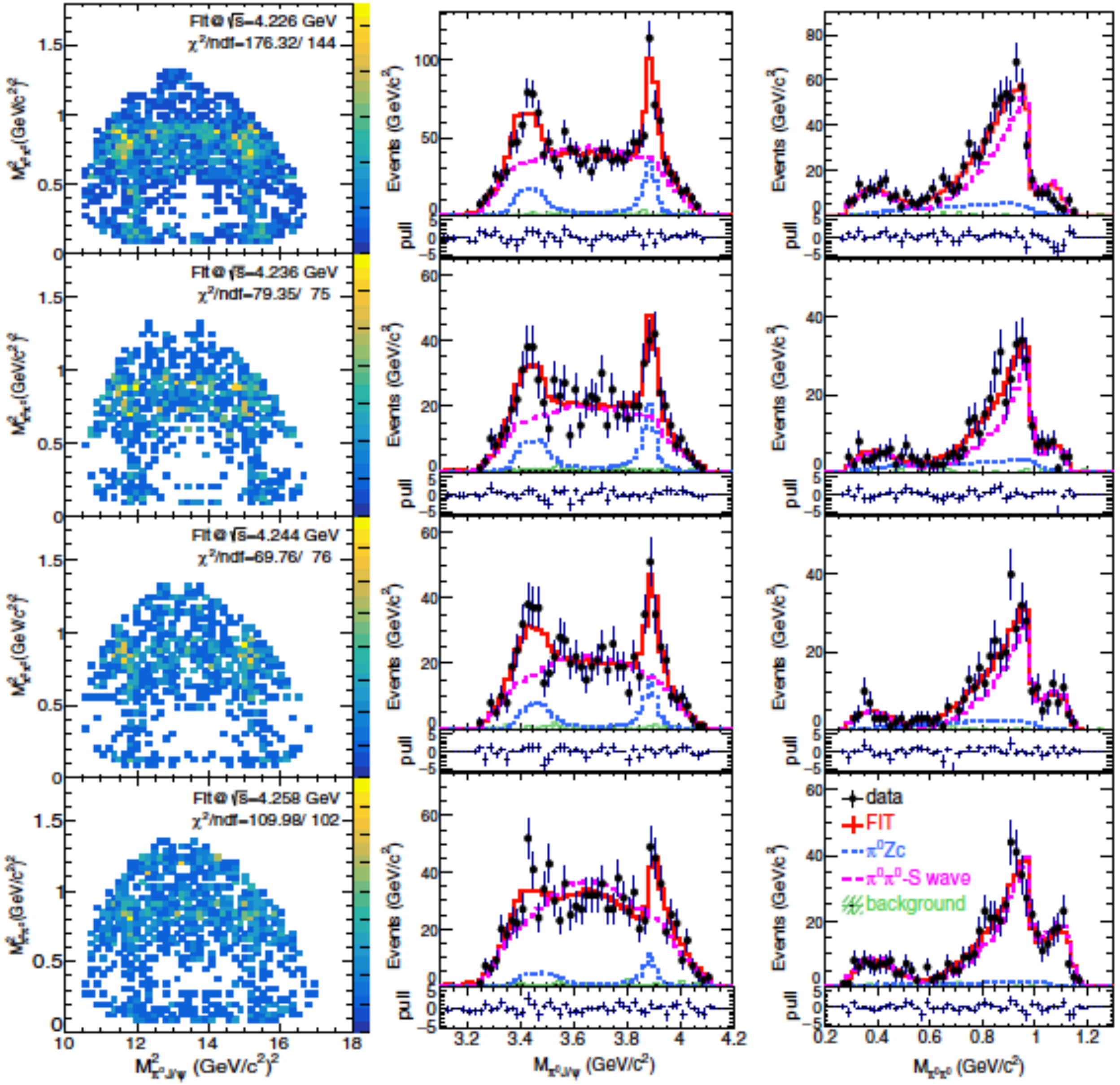
  g_2'/g_1'=27.1±2.0±1.9

  Which corresponding to pole Mass= (3881.2±4.2±52.7)MeV, pole width=(51.8±4.6±36.0)MeV

- **J^p of Zc favor to be 1^+ with statistical significance larger than7σ over other quantum numbers**
- **The significance of Zc(4020) process is found to be 3σ**

PWA of $e^+e^- \rightarrow \pi^0\pi^0 J/\psi$

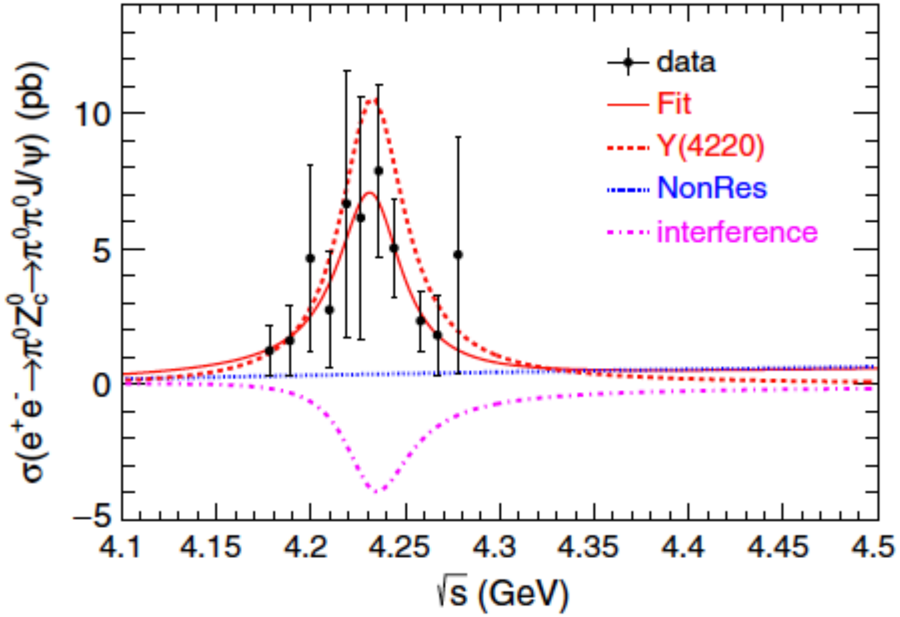
PRD 102, 012009 (2020)



Simultaneous fit of 4 energy points near Y(4230).

J^p of Zc^0 favor to be 1^+ confirmed

$\sigma(e^+e^- \rightarrow \pi^0 Z_c^0 \rightarrow \pi^0\pi^0 J/\psi)$

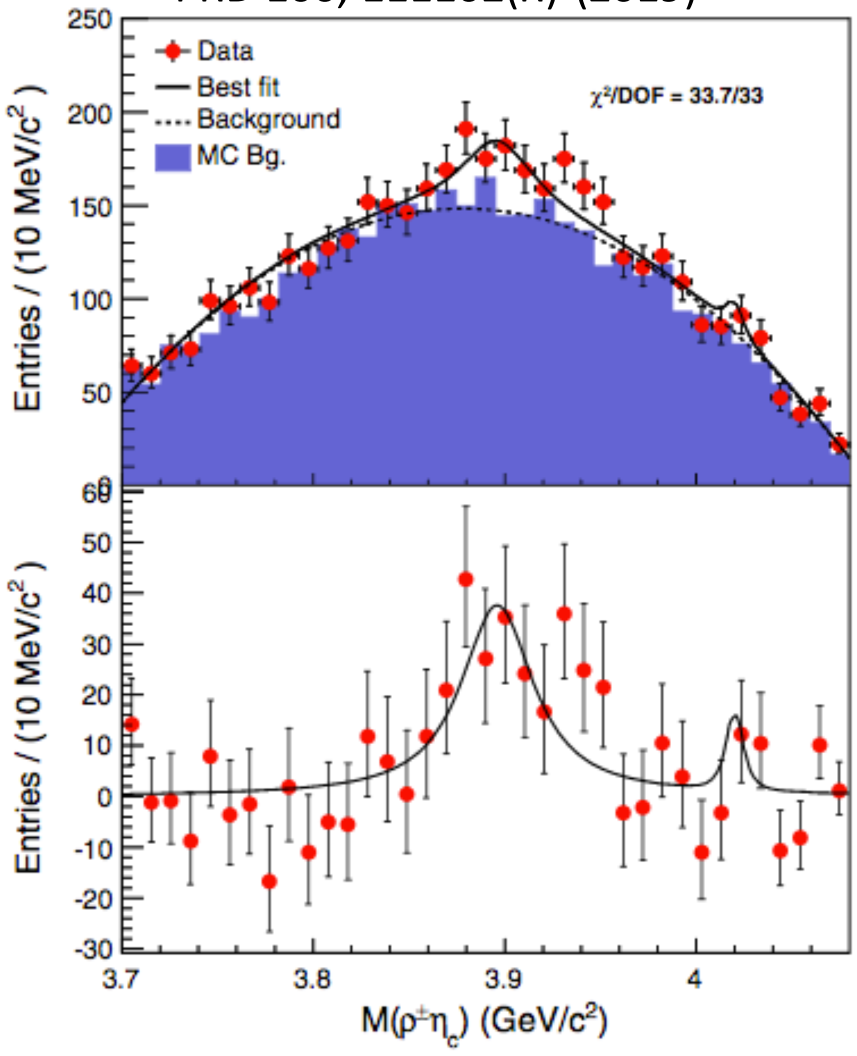


- **A hint of correlation between Y(4220) and Zc(3900)**

Parameters	Solution I	Solution II
$p_0(c^2/\mathrm{MeV})$	0.0 ± 11.3	
p_1	$(1.8 \pm 1.9) \times 10^{-2}$	
$M(R)\,(\mathrm{MeV}/c^2)$	4231.9 ± 5.3	
$\Gamma_{tot}(R))\,(\mathrm{MeV})$	41.2 ± 16.0	
$\Gamma_{ee}\mathcal{B}_{R\to\pi^0 Z_c(3900)^0}\,(\mathrm{eV})$	0.53 ± 0.15	0.22 ± 0.25
$\phi(R)$	$(-103.9 \pm 33.9)^\circ$	$(112.7 \pm 43.0)^\circ$

Evidence of $\mathbf{e^+e^-} \rightarrow \pi Z_c^{(\prime)}, Z_c^{(\prime)} \rightarrow \rho^{\pm}\eta_c$

PRD 100, 111102(R) (2019)



- **Nine η_c channels are used to reconstruct η_c.**
- **After the η_c and ρ mass window, a hint of $Z_c(3900)$ peak can be seen on the recoiled mass of the bachelor π.**
- **The blue histogram is η_c sideband. Z_c parameter are fixed to latest measurement.**

- **Strong evidence of Zc(3900) →$\rho\eta_c$ is observed at √s=4.23GeV, with statistical significance 4.3σ(3.9σ including systematic uncertainty)**
- **No significant Zc'(4020)→$\rho\eta_c$ observed. (statistical significance 1.0σ)**

R_{Zc}=Br($Z_c \rightarrow \rho\eta_c$)/Br($Z_c \rightarrow \pi J/\psi$)

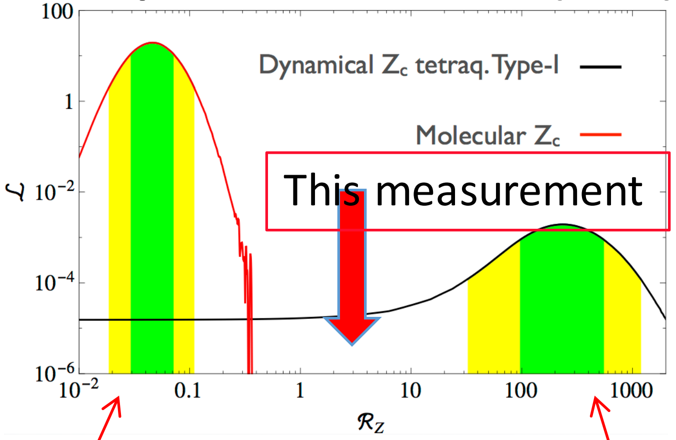
TABLE III. Comparison of the measured $R_{Z_c(3900)}$ and $R_{Z_c(4020)}$ with the theoretical predictions.

Ratio	Measurement	Tetraquark	Molecule
$R_{Z_c(3900)}$	2.3 ± 0.8 [29]	230^{+330}_{-140} [12]	$0.046^{+0.025}_{-0.017}$ [12]
		$0.27^{+0.40}_{-0.17}$ [12]	1.78 ± 0.41 [17]
		0.66 [13]	6.84×10^{-3} [18]
		0.56 ± 0.24 [14]	0.12 [19]
		0.95 ± 0.40 [15]	
		1.08 ± 0.88 [16]	
		1.28 ± 0.37 [17]	
		1.86 ± 0.41 [17]	
$R_{Z_c(4020)}$	<1.2 [4]	$6.6^{+56.8}_{-5.8}$ [12]	$0.010^{+0.006}_{-0.004}$ [12]

BESIII result

Theoretical prediction

A.Esposito et.al., PLB 746(2015), 194-201

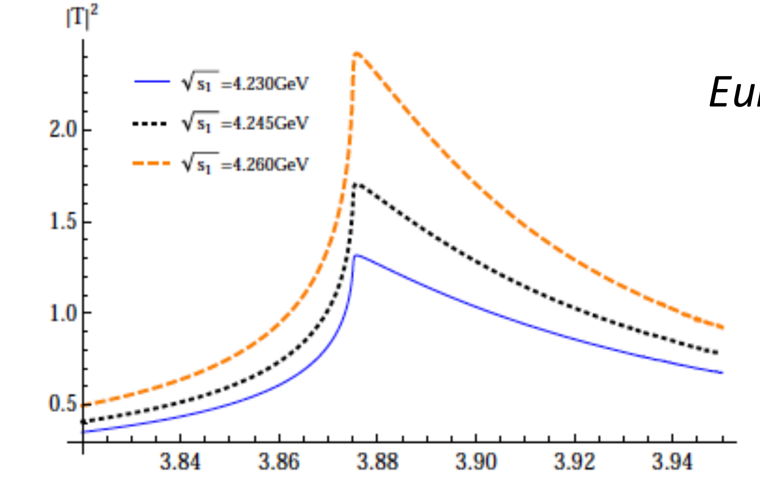


This measurement

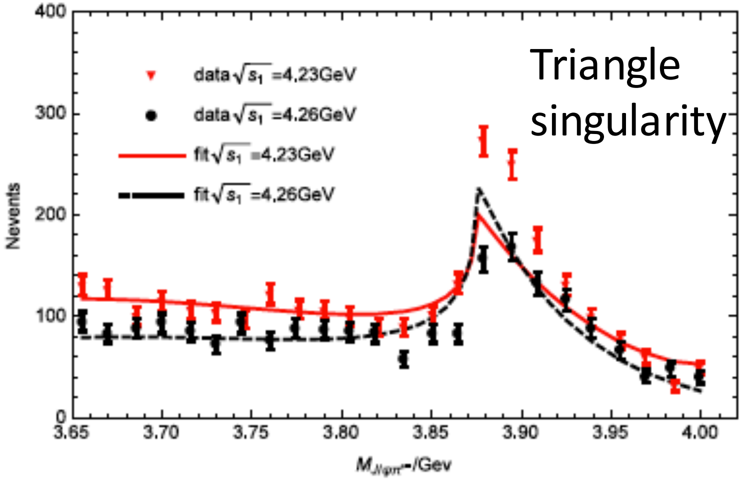
Molecular Zc

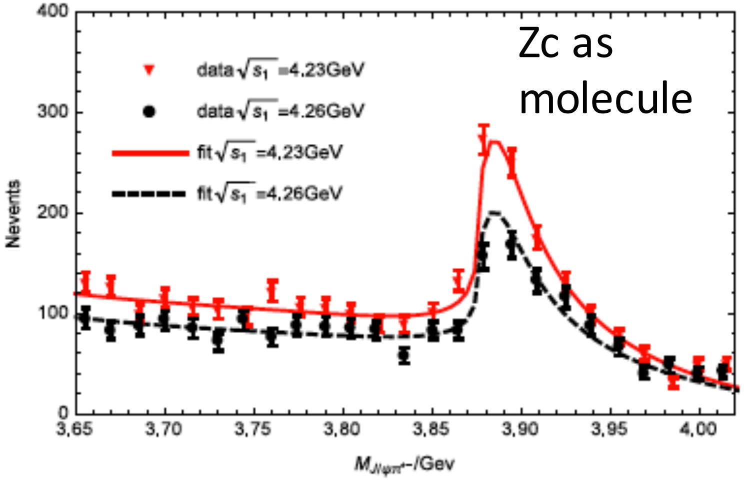
Tetraquak Type-1

Lineshape at different energy points



Eur.Phys.J.C 78 (2018) 4, 276





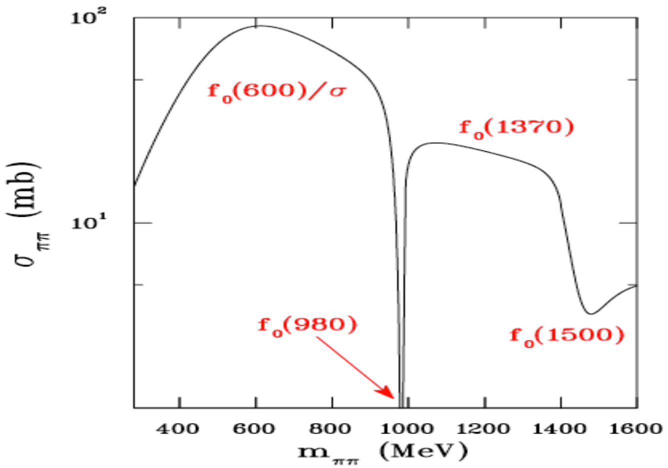
The line shape of Zc agree Better with Zc as molecule.

Challenge in the PWA of XYZ data

- Ambiguity in $\pi\pi$ parametrization:

  Sum of Breit-wigners, N/D method, K-matrix method.

  Different method causing big difference to Zc result.

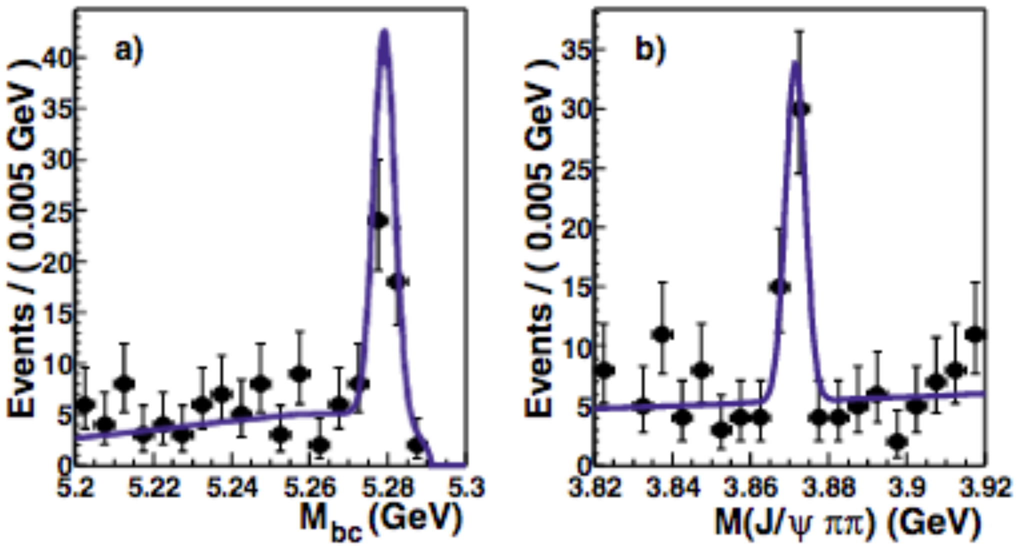


- Parameterization of Zc: BW, Flatte, Theoretical model dependent line-shape.

- Coherently understanding of all energy points and all data channels.

Part III: X(3872)

About X(3872)



- X(3872) was first observed in 2003 by Belle, PRL 91.262001 (2003)
  In $B^+ \to K^+ \pi^+\pi^- J/\psi$
- $J^{PC}=1^{++}$ *(CDF, LHCb)*

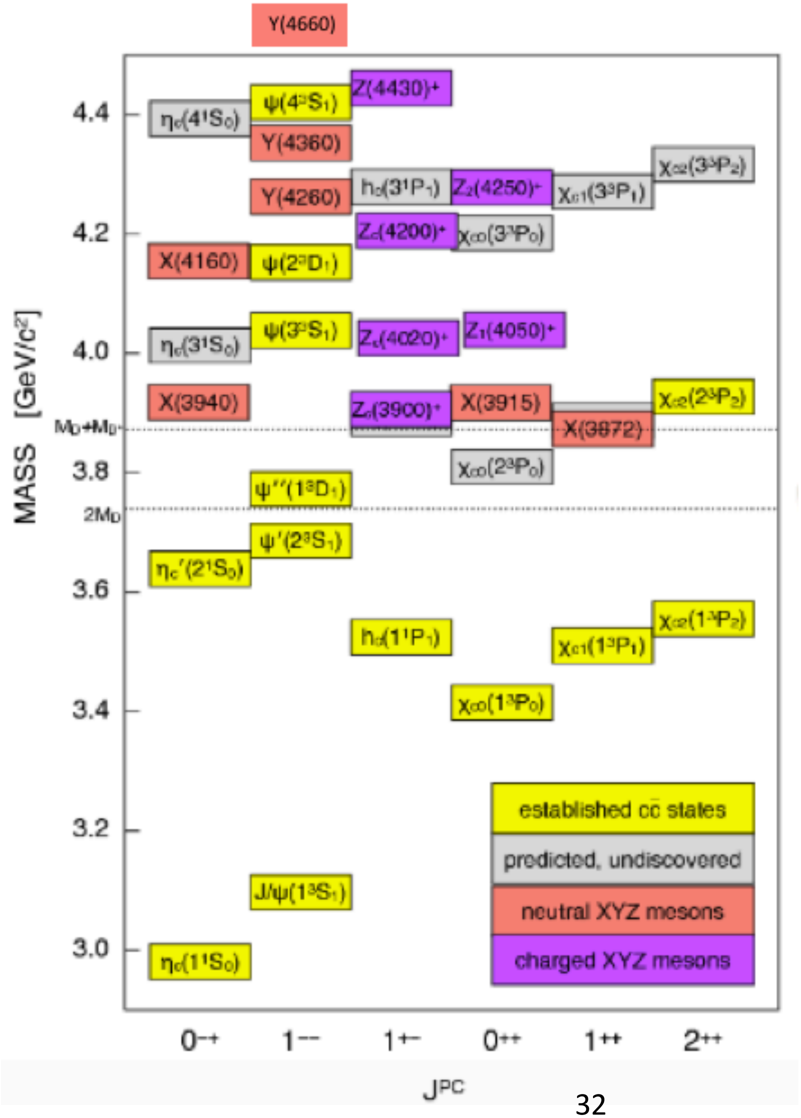
- Most recent measurement of mass/width by LHCb: arXiv:2005.13419

Breit-wigner

$$m_{\chi_{c1}(3872)} = 3871.695 \pm 0.067 \pm 0.068 \pm 0.010\,\text{MeV}$$

$$\Gamma_{\text{BW}} = 1.39 \pm 0.24 \pm 0.10\,\text{MeV}$$

◆ Very close to threshold : M($D^0\bar{D}^{*0}$)=3871.70±0.11 MeV



Determination of the absolute branching fractions of X(3872) decays

- PRD.100.094003(2019)

Fitting to the measured branching fraction give by different Collaborations.
The average branching fraction of X(3872) decay.

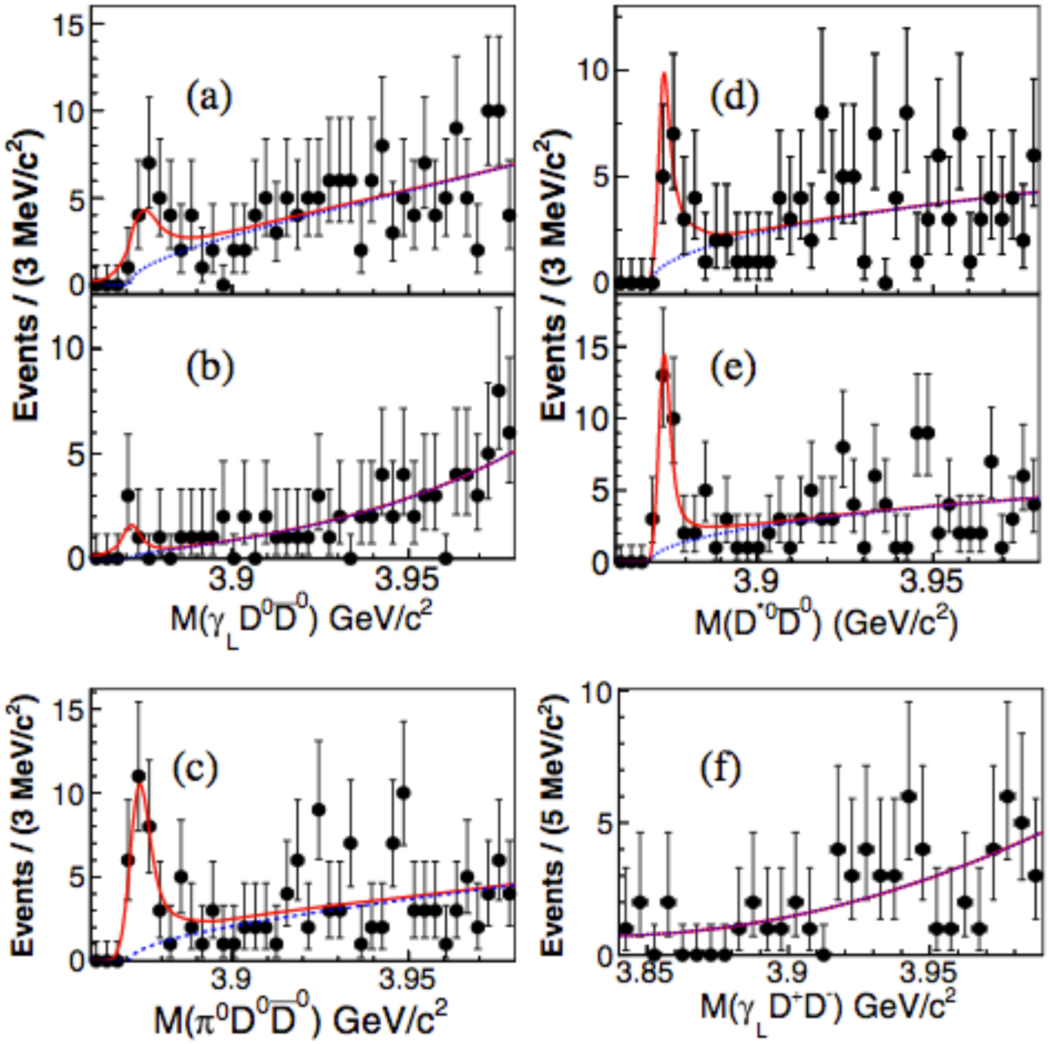
$\chi_{c1}(3872)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	e^+e^-	
Γ_2	$\pi^+\pi^- J/\psi(1S)$	> 3.2 %
Γ_3	$\rho^0 J/\psi(1S)$	
Γ_4	$\omega J/\psi(1S)$	> 2.3 %
Γ_5	$D^0 \overline{D}{}^0 \pi^0$	>40 %
Γ_6	$\overline{D}{}^{*0} D^0$	>30 %
Γ_7	$\gamma\gamma$	
Γ_8	$D^0 \overline{D}{}^0$	
Γ_9	$D^+ D^-$	
Γ_{10}	$\gamma\chi_{c1}$	
Γ_{11}	$\gamma\chi_{c2}$	
Γ_{12}	$\pi^0\chi_{c2}$	
Γ_{13}	$\pi^0\chi_{c1}$	> 2.8 %
Γ_{14}	$\pi^0\chi_{c0}$	
Γ_{15}	$\gamma J/\psi$	$> 7 \times 10^{-3}$
Γ_{16}	$\gamma\psi(2S)$	> 4 %
Γ_{17}	$\pi^+\pi^-\eta_c(1S)$	not seen
Γ_{18}	$\pi^+\pi^-\chi_{c1}$	not seen
Γ_{19}	$p\overline{p}$	not seen

PDG

Parameter index	Decay mode	Branching fraction
1	$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \to D^{*0}\bar{D}^0 + \text{c.c.}$	$(52.4^{+25.3}_{-14.3})\%$
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	$B^+ \to X(3872)K^+$	$(1.9 \pm 0.6) \times 10^{-4}$
8	$B^0 \to X(3872)K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
	$X(3872) \to \text{unknown}$	$(31.9^{+18.1}_{-31.5})\%$

X(3872) exclusive decay modes evidence of X(3872)→$\gamma J/\psi$



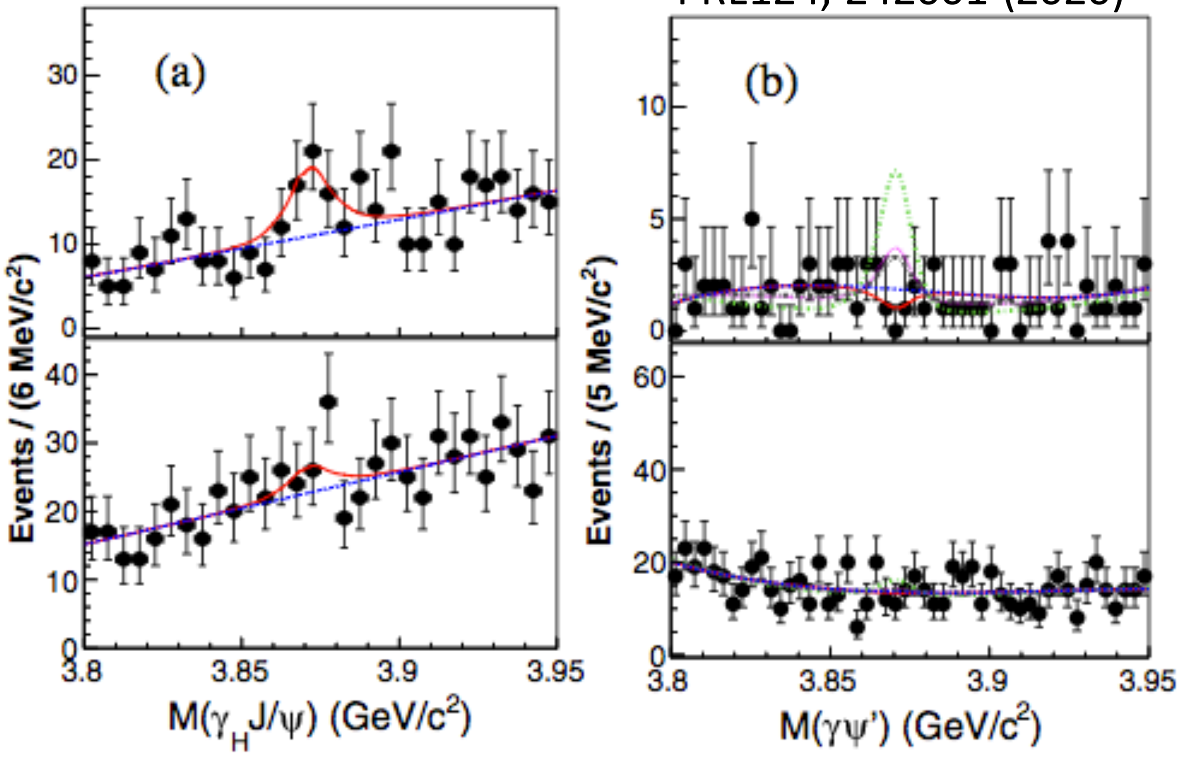
PRL124, 242001 (2020)

TABLE I. Relative branching ratios and UL on branching ratios compared with $X(3872) \to \pi^+\pi^- J/\psi$ [18,27], where systematic uncertainties have been taken into account.

Mode	Ratio	UL
$\gamma J/\psi$	0.79 ± 0.28	...
$\gamma\psi'$	-0.03 ± 0.22	< 0.42
$\gamma D^0 \bar{D}^0$	0.54 ± 0.48	< 1.58
$\pi^0 D^0 \bar{D}^0$	-0.13 ± 0.47	< 1.16
$D^{*0}\bar{D}^0$ + c.c.	11.77 ± 3.09	...
$\gamma D^+ D^-$	$0.00^{+0.48}_{-0.00}$	< 0.99
$\omega J/\psi$	$1.6^{+0.4}_{-0.3} \pm 0.2$ [18]	...
$\pi^0 \chi_{c1}$	$0.88^{+0.33}_{-0.27} \pm 0.10$ [27]	...

Evidence of X(3872)→$\gamma J/\psi$

PRL124, 242001 (2020)



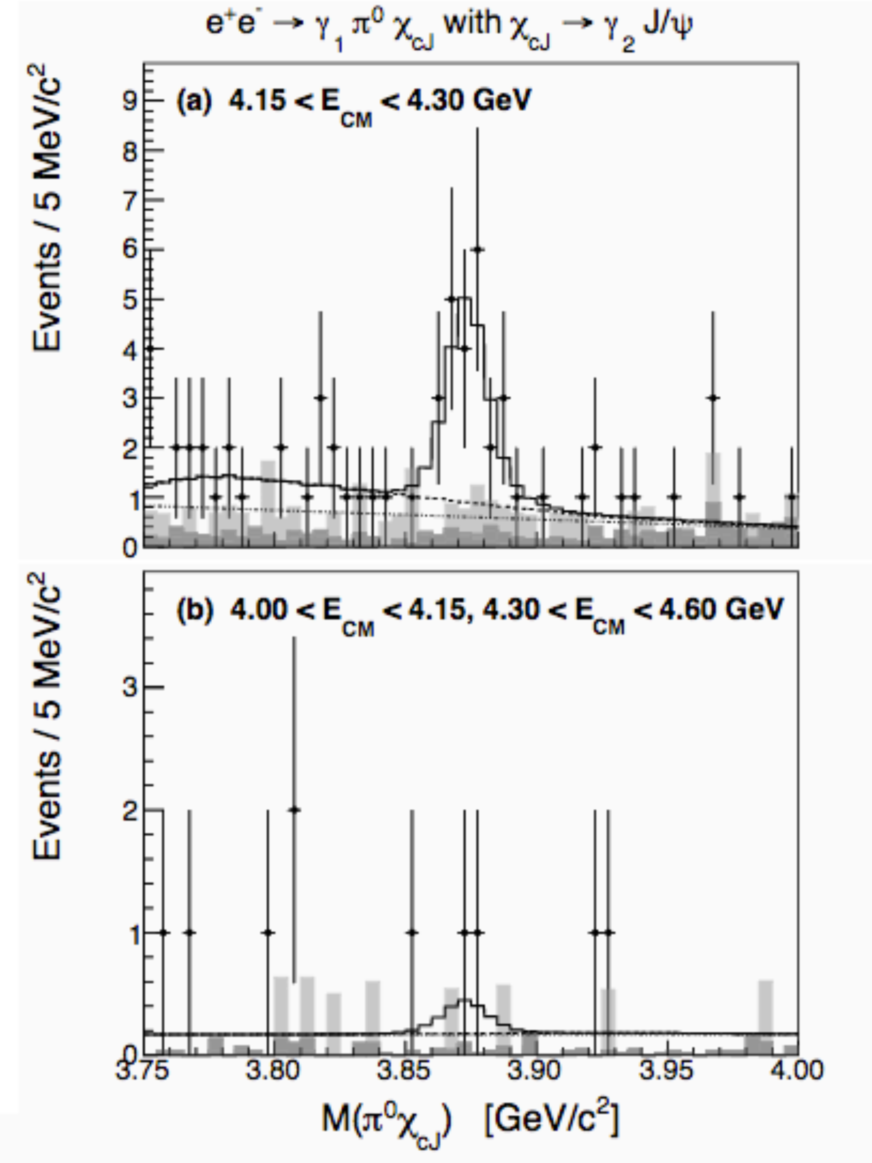
- *Improved uplimit of* $R_{\psi}=\frac{B[X(3872)\to\gamma\psi']}{B[X(3872)\to\gamma J\psi]}$<0.59

- **Previous measurement of R_{ψ}**
  BaBar: 3.4±1.4
  LHCb: 2.46±0.64±0.29
  Belle: <2.1 (CL. 90%)

- **If BaBar or LHCb's result are correct, X(3872) prefer to be a charmonium**

- **If the result of BESIII is correct, X(3872) prefere to be molecule**
  or a combination of molecule and charmonium.

Observation of X(3872) → $\pi^0\chi_{c1}(1P)$



PRL122,202001 (2019)

- **Data sets used:**

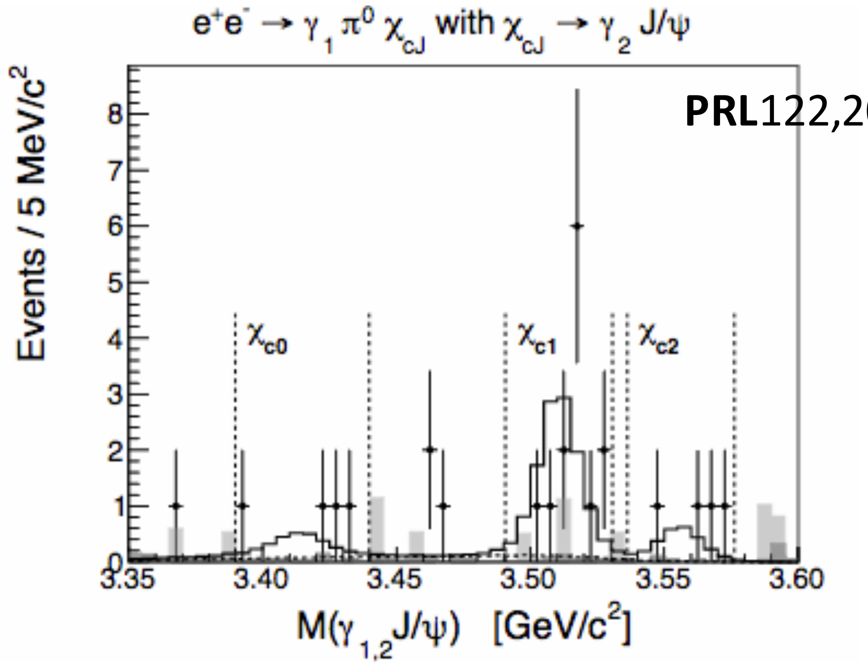
9.0fb^{-1} for 4.15<E_{cm}<4.30 GeV
0.7fb^{-1} for 4.00<E_{cm}<4.15 GeV
2.8fb^{-1} for 4.30<E_{cm}<4.60 GeV

- **With in range of 4.15<E_{cm}<4.30 GeV**

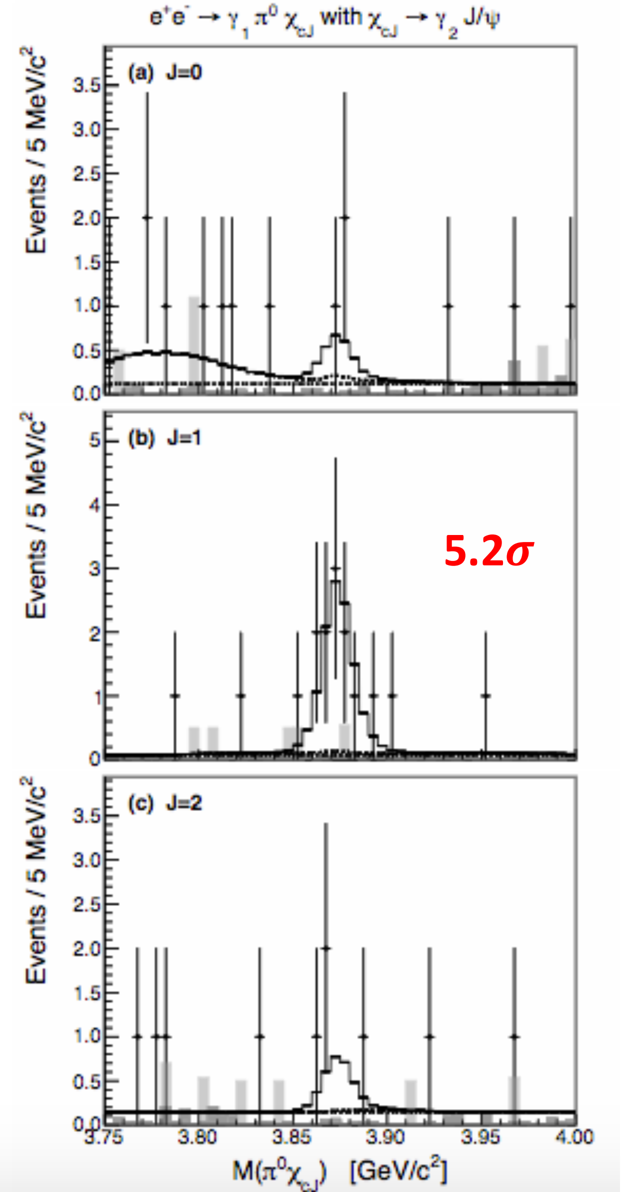
For the sum of events in all the three χ_{cJ} range, a clear X(3872) signal is seen with events number=$16.9^{+5.2}_{-4.5}$, and Significance= 4.8σ

- **No evidence of X(3872) in other E_{cm}**

Observation of X(3872) $\rightarrow \pi^0\chi_{c1}(1P)$



PRL122,202001 (2019)



- **$10.8^{+3.8}_{-3.1}$ X(3872) signal observed in χ_{c1} range with statistical significance 5.2σ**

- **The branching ratio**

$R_J = B(X \rightarrow \pi^0\chi_{c1})/B(X \rightarrow \pi^+\pi^- J/\psi)$

R_0<19 (90% U.L.)

$R_1=0.88^{+0.33}_{-0.27} \pm 0.10$

R_2<1.1 (90% U.L.)

Comparison between experiment and theory

- If we use the previous fitted $Br(X(3872) \to \pi^0 \chi_{c1})$

Parameter index	Decay mode	Branching fraction
1	$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \to D^{*0}\bar{D}^0 + \text{c.c.}$	$(52.4^{+25.3}_{-14.3})\%$
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	$X(3872) \to \pi^0\chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$

- If X(3872) were the $\chi_{c1}(2p)$ state of charmonium, then

From the estimation of [Dubynskiy, Voloshin, PRD 77, 014013 (2008)],

$$\Gamma(X(3872) \to \pi^0 \chi_{cJ}) \sim 0.06\ keV$$

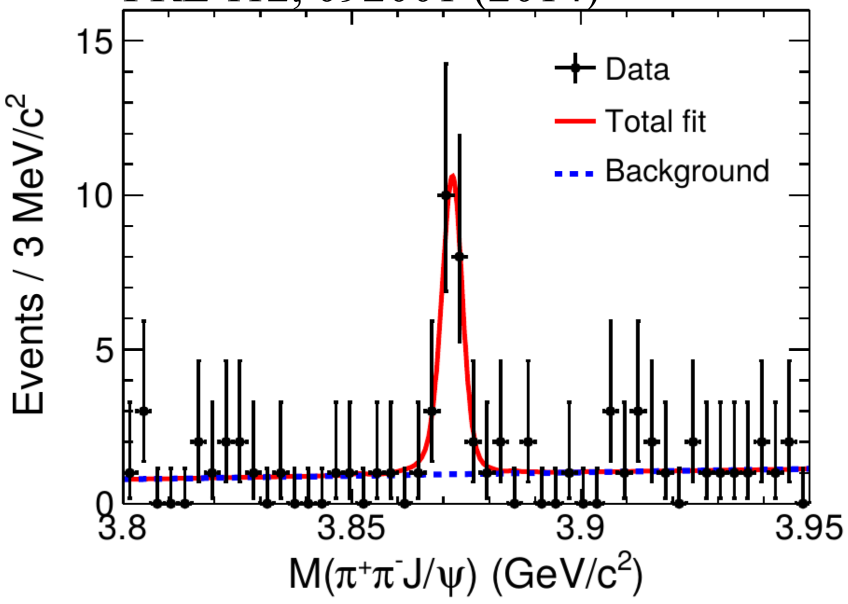
Which would imply an unrealistically small

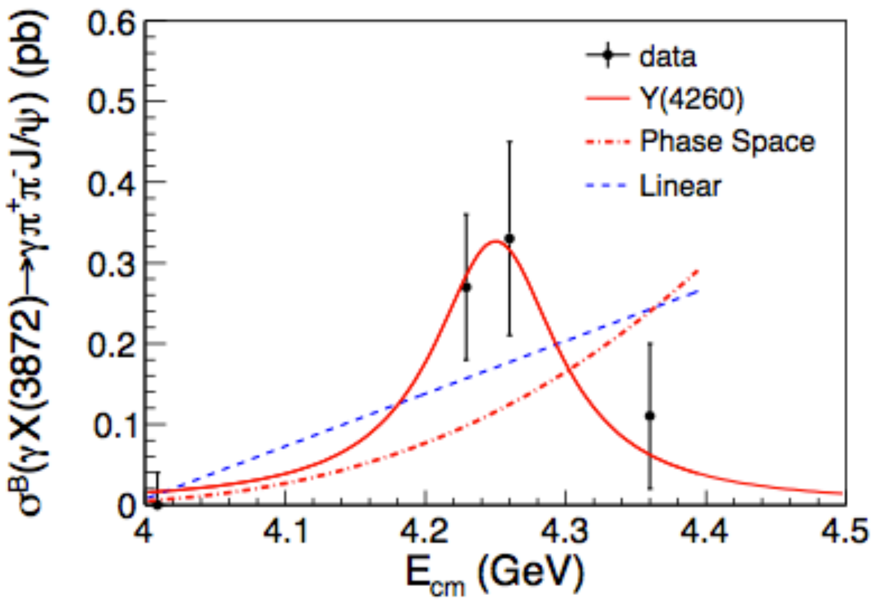
$$\Gamma_{TOT}(X(3872)) \sim 1.7 keV$$

- So this measurement disfavor the $\chi_{c1}(2p)$ interpretation of the X(3872).

$e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$

PRL 112, 092001 (2014)

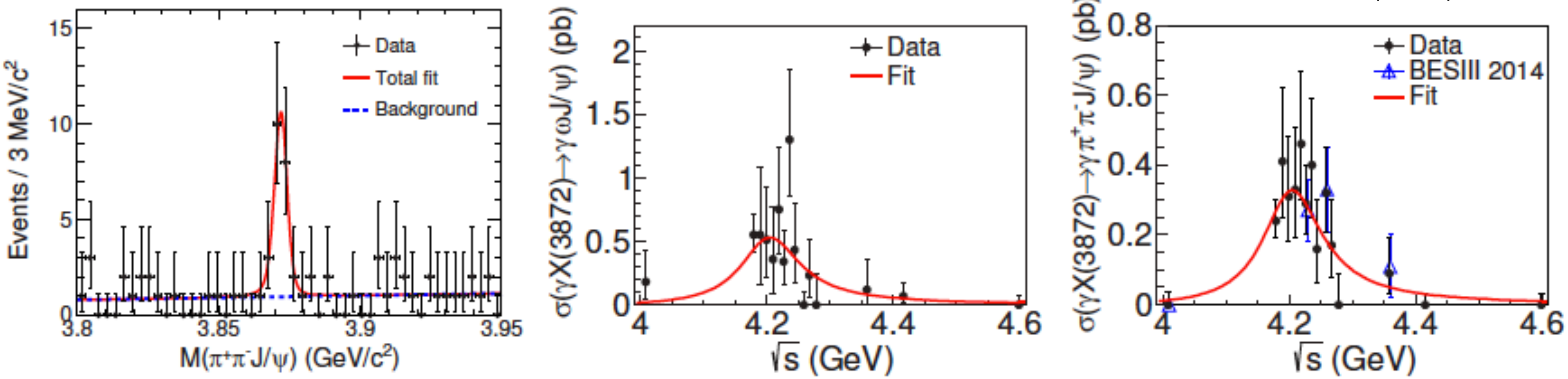




- BESIII observed $e^+e^- \rightarrow \gamma X(3872)$, $X(3872) \rightarrow \pi^+\pi^- J/\psi$.
- $e^+e^- \rightarrow \gamma X(3872)$ → Charge parity of X(3872)=+1.
- It seems that $X(3872)$ is from the radiative transition of $Y(4260)$

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

PRL122,232002 (2019)



(1). Cross section measurement of $e^+e^- \rightarrow \gamma X(3872)$ for (mid) $\omega J/\psi$ and (right) $\pi^+\pi^- J/\psi$ channel

(2). Simultaneous fit to the cross section with a single Breit-Wigner resonance

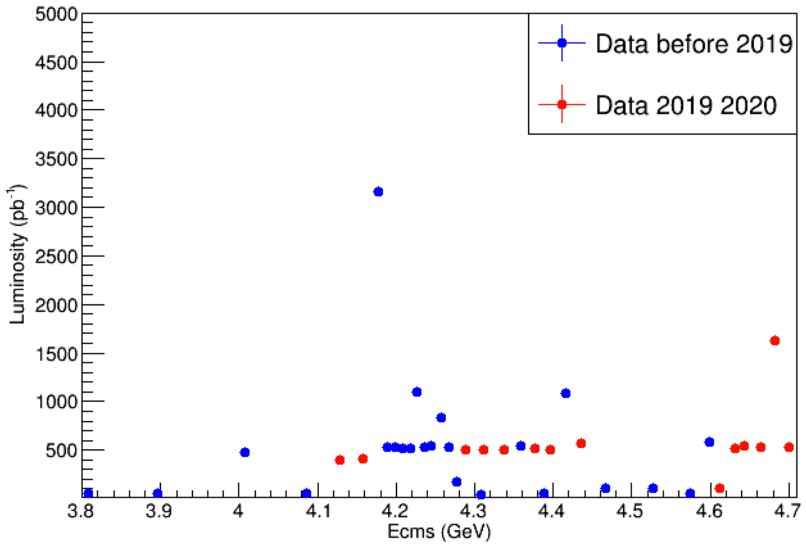
$$M[Y(4200)] = 4200.6^{+7.9}_{-13.3} \pm 3.0 \text{ MeV}/c^2$$

$$\Gamma[Y(4200)] = 115^{+38}_{-26} \pm 12 \text{ MeV}$$

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

prospect

- At the summer of 2019, BEPCII has made a small upgrade to increase the beam energy up to 2.45GeV (Ecm=4.9 GeV). And the upgrade of luminosity by a factor of 2 is under discussion



- BESIII has taken more data points around E_{cm}=4.23GeV and above 4.6GeV. More precise cross section shape can be obtained.
- And more states can be searched in higher energy region. Search for Zcs, Zc(4430),Y(4660) at BESIII

Summary

- A lot of observation of structures from experiment
- More precise measurement of states parameters
- More decay channels observed
- Now we have more constrains for the theoretical models.

- 1777(Oxygen named)→1869(the periodic table of elements)→1897(electron discovered)→1918(proton discovered)→1932(neutron discovered)
- Which stage are we at?