other XYZ states

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XYZ Workshop

2013/05/10

Outline

1. 1^{--} Y states
2. C=+ XY states
3. Some Z states
4. Summary

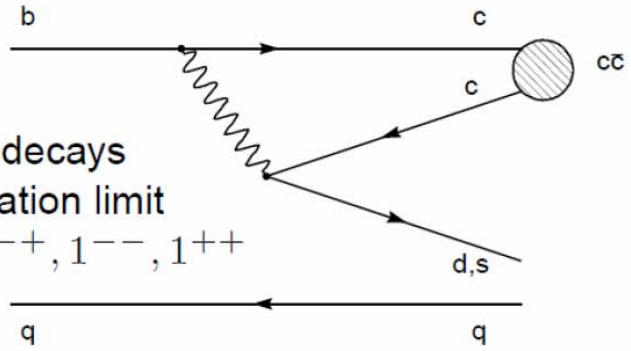
arXiv:1010.5827

Many XYZ states in these years !

State	m (MeV)	Γ (MeV)	J^{PC}	Process (mode)	Experiment ($\#\sigma$)	Year	Status
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6 (<2.2)	$1^{++}/2^{-+}$	$B\to K(\pi^+\pi^- J/\psi)$	Belle [85, 86] (12.8), *BABAR* [87] (8.6)	2003	OK
				$p\bar{p}\to(\pi^+\pi^- J/\psi)+...$	CDF [88–90] (np), DØ [91] (5.2)		
				$B\to K(\omega J/\psi)$	Belle [92] (4.3), *BABAR* [93] (4.0)		
				$B\to K(D^{*0}\bar{D}^0)$	Belle [94, 95] (6.4), *BABAR* [96] (4.9)		
				$B\to K(\gamma J/\psi)$	Belle [92] (4.0), *BABAR* [97, 98] (3.6)		
				$B\to K(\gamma\psi(2S))$	*BABAR* [98] (3.5), Belle [99] (0.4)		
$X(3915)$	3915.6 ± 3.1	28 ± 10	$0/2^{?+}$	$B\to K(\omega J/\psi)$	Belle [100] (8.1), *BABAR* [101] (19)	2004	OK
				$e^+e^-\to e^+e^-(\omega J/\psi)$	Belle [102] (7.7)		
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [103] (6.0)	2007	NC!
				$e^+e^-\to J/\psi\ (...)$	Belle [54] (5.0)		
$G(3900)$	3943 ± 21	52 ± 11	1^{--}	$e^+e^-\to\gamma(D\bar{D})$	*BABAR* [27] (np), Belle [21] (np)	2007	OK
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^- J/\psi)$	Belle [104] (7.4)	2007	NC!
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$B\to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4140)$	4143.4 ± 3.0	15^{+11}_{-7}	$?^{?+}$	$B\to K(\phi J/\psi)$	CDF [106, 107] (5.0)	2009	NC!
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$e^+e^-\to J/\psi(D\bar{D}^*)$	Belle [103] (5.5)	2007	NC!
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$B\to K(\pi^+\chi_{c1}(1P))$	Belle [105] (5.0)	2008	NC!
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^- J/\psi)$	*BABAR* [108, 109] (8.0)	2005	OK
					CLEO [110] (5.4)		
					Belle [104] (15)		
				$e^+e^-\to(\pi^+\pi^- J/\psi)$	CLEO [111] (11)		
				$e^+e^-\to(\pi^0\pi^0 J/\psi)$	CLEO [111] (5.1)		
$Y(4274)$	$4274.4^{+8.4}_{-6.7}$	32^{+22}_{-15}	$?^{?+}$	$B\to K(\phi J/\psi)$	CDF [107] (3.1)	2010	NC!
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$e^+e^-\to e^+e^-(\phi J/\psi)$	Belle [112] (3.2)	2009	NC!
$Y(4360)$	4353 ± 11	96 ± 42	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$	*BABAR* [113] (np), Belle [114] (8.0)	2007	OK
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$B\to K(\pi^+\psi(2S))$	Belle [115, 116] (6.4)	2007	NC!
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$e^+e^-\to\gamma(\Lambda_c^+\Lambda_c^-)$	Belle [25] (8.2)	2007	NC!
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$e^+e^-\to\gamma(\pi^+\pi^-\psi(2S))$	Belle [114] (5.8)	2007	NC!
$Y_b(10888)$	10888.4 ± 3.0	$30.7^{+8.9}_{-7.7}$	1^{--}	$e^+e^-\to(\pi^+\pi^-\Upsilon(nS))$	Belle [37, 117] (3.2)	2010	NC!

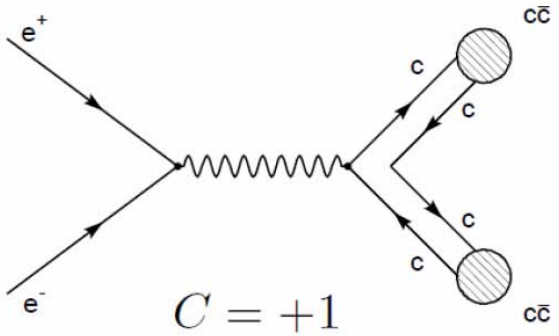
Exotic States Production

B decay



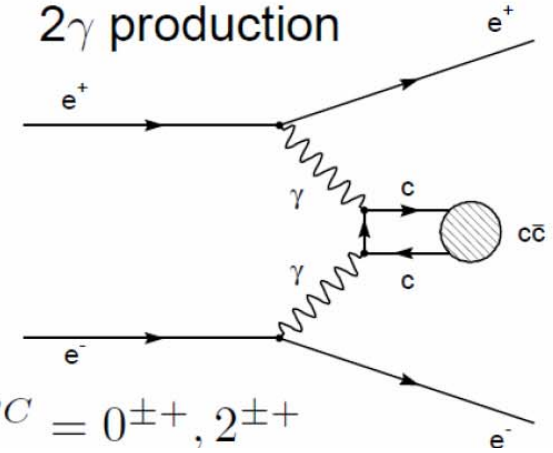
in 2-body decays
in factorization limit
$J^{PC} = 0^{-+}, 1^{--}, 1^{++}$

Double charmonium production



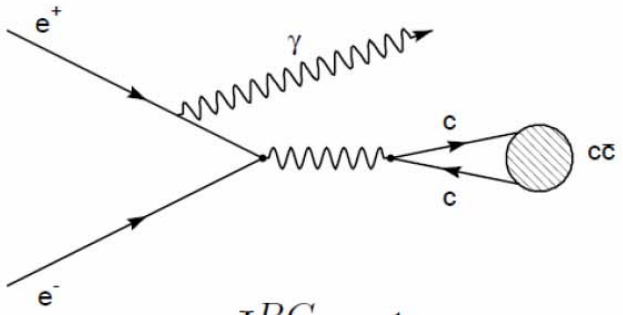
$C = +1$

2γ production



$J^{PC} = 0^{\pm+}, 2^{\pm+}$

Initial State Radiation (ISR)

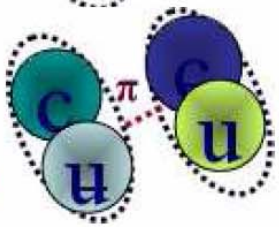


$J^{PC} = 1^{--}$

Exotic charmonium-like states

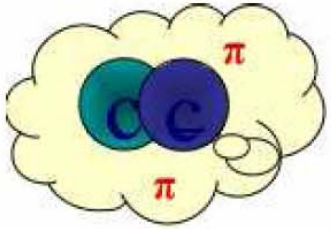
Tetraquark:
four tightly bound quarks

Molecular state:
two loosely bound mesons



Hybrid: states with
excited gluonic degrees of freedom

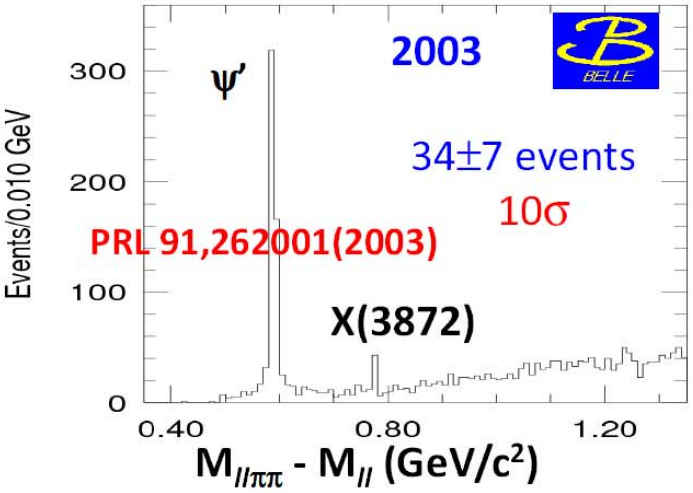
Hadrocharmonium: charmonium state,
"coated" by excited light-hadron matter



Exotics signature:
- J^{PC}, forbidden for charmonium
- Extremely narrow width for a state above $D\bar{D}$
- Non-zero charge, strangeness

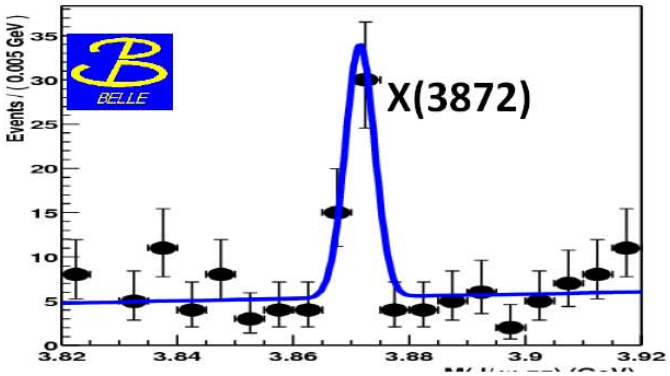
X(3872) Most famous $c\bar{c}$ (-like) state

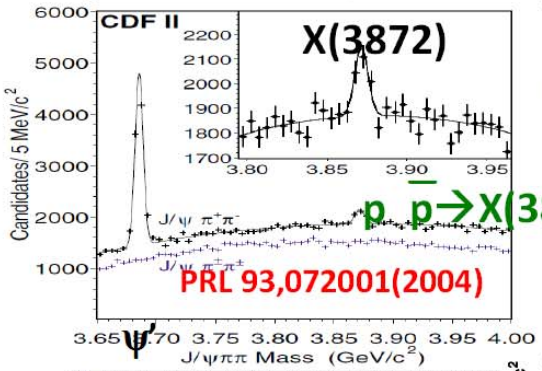
Discovered by Belle in $J/\psi\pi\pi$ decay mode

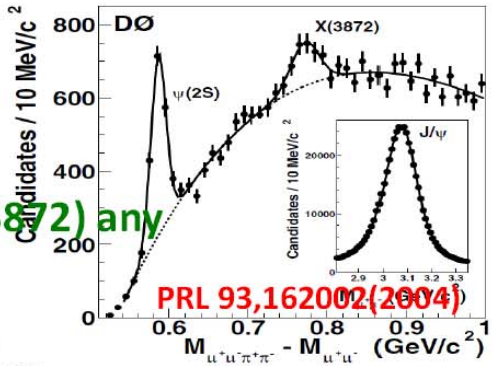


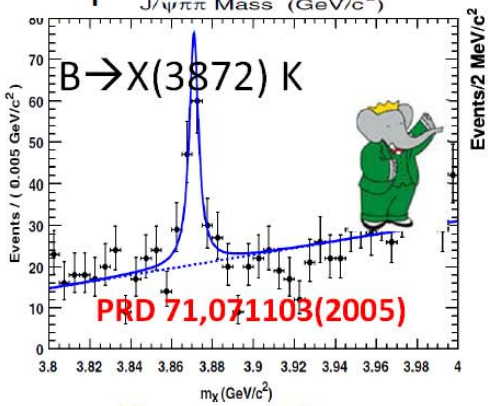
$B^+ \rightarrow X(3872) K^+$, $X(3872) \rightarrow J/\psi\pi^+\pi^-$

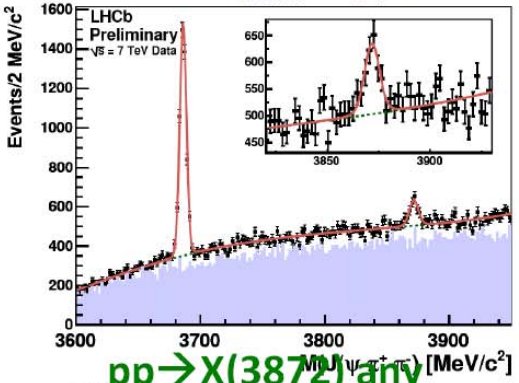
Γ<2.5 MeV (90%CL)



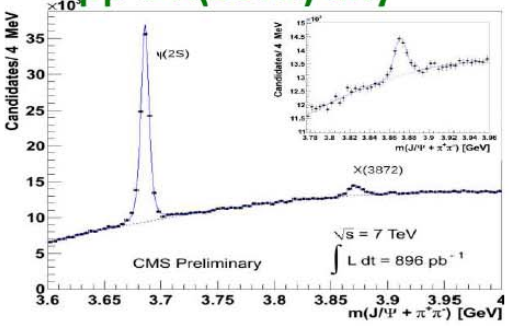








Confirmed by CDF, DO, BaBar, CMS and LHCb.



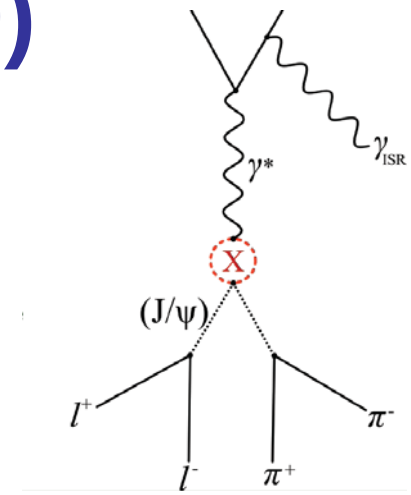
Difficult to place as conventional charmonium state.

1^{--} Y states

Y(4008), Y(4260)

Exotic charmonium-like states above open-charm threshold

- Need no introduction here!
- Focus primarily on the "Y" candidates: $J^{PC}= 1^{--}$

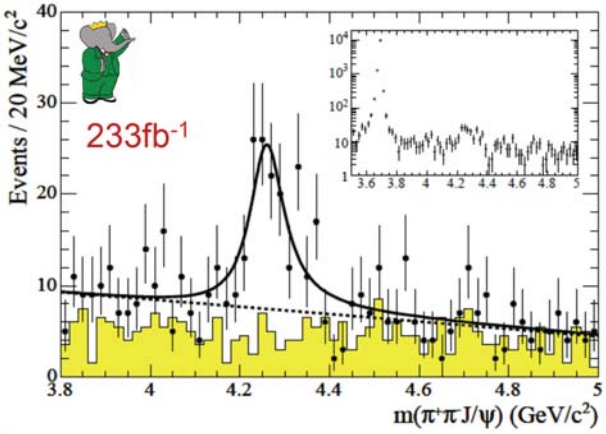


BaBar: Y(4260) observation

- PRL 95, 142001 (2005)
- 8σ enhancement with ISR method

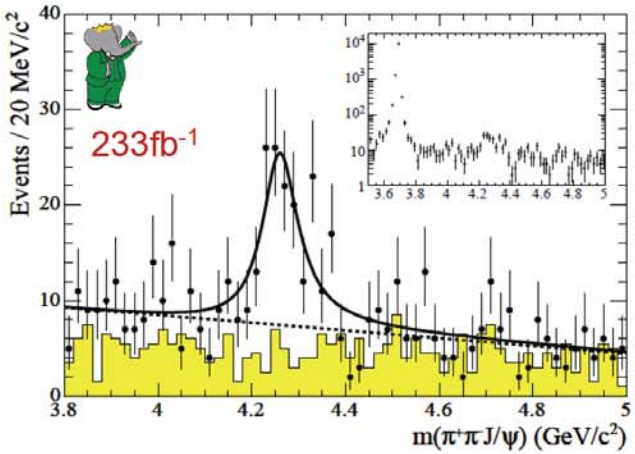
Production technique

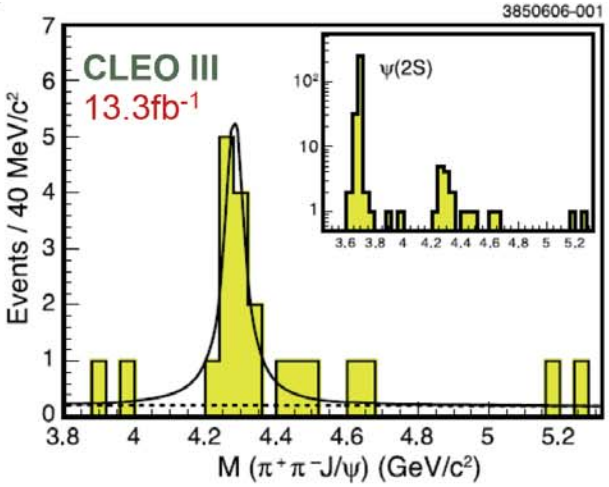
- Pseudo-direct production in ISR events
- Look at strong decay modes strongly suppressed for charmonium above threshold [such as $Y \rightarrow \pi^+\pi^- J/\psi$]

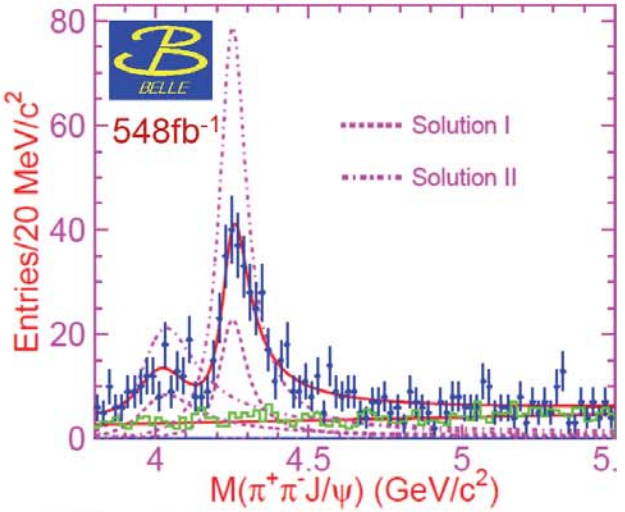


$$m_{Y(4260)} = (4259 \pm 8^{+2}_{-6}) MeV/c^2$$
$$\Gamma_{Y(4260)} = (88 \pm 23^{+6}_{-4}) MeV$$

Previous Y(4008), Y(4260) results







BaBar: Y(4260) observation

- PRL 95, 142001 (2005)
- 8σ enhancement with ISR method

$$m_{Y(4260)} = (4259 \pm 8^{+2}_{-6})MeV/c^2$$
$$\Gamma_{Y(4260)} = (88 \pm 23^{+6}_{-4})MeV$$

CLEO: Y(4260) confirmation

- CLEO III: ISR method [pictured]
- PRD 74, 091104(R) (2006)
- CLEO-c: scan/direct production
- PRL 96, 162003 (2006)
- $\pi^0\pi^0$ mode implies 0 isospin

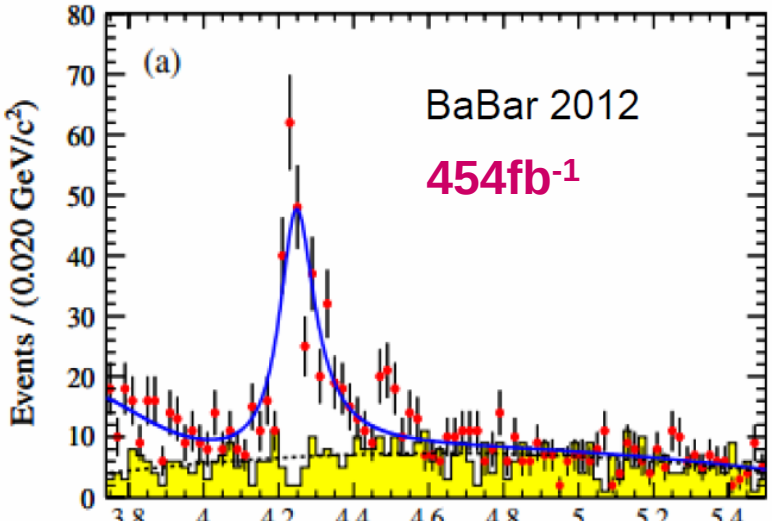
$$m_{Y(4260)} = (4284 \pm 4^{+17}_{-16})MeV/c^2$$
$$\Gamma_{Y(4260)} = (73 \pm 5^{+39}_{-25})MeV$$

Belle: Y(4260) + Y(4008)

- ISR method
- PRD 99, 182004 (2007)
- Second enhancement Y(4008)

$$m_{Y(4260)} = (4247 \pm 12^{+17}_{-32})MeV/c^2$$
$$\Gamma_{Y(4260)} = (108 \pm 19 \pm 10)MeV$$
$$m_{Y(4008)} = (4008 \pm 40^{+114}_{-28})MeV/c^2$$
$$\Gamma_{Y(4008)} = (226 \pm 44 \pm 87)MeV$$

Updated Y(4260) results from Babar



$\pi^+\pi^- J/\psi$ invariant mass plot

- Clear Y(4260) peak
- Background [yellow] is interpolated from J/ψ sidebands in m(l^+l^-) distribution
- **Where is the Y(4008)?**
- **What is the enhancement at the low end?**
- **Y(4260) results consistent with Belle**

Belle 2007

$$m_{Y(4260)} = (4247 \pm 12^{+17}_{-32}) MeV/c^2$$

$$\Gamma_{Y(4260)} = (108 \pm 19 \pm 10) MeV$$

$$m_{Y(4008)} = (4008 \pm 40^{+114}_{-28}) MeV/c^2$$

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

BaBar 2012

$$m_{Y(4260)} = (4244 \pm 5 \pm 4) MeV/c^2$$

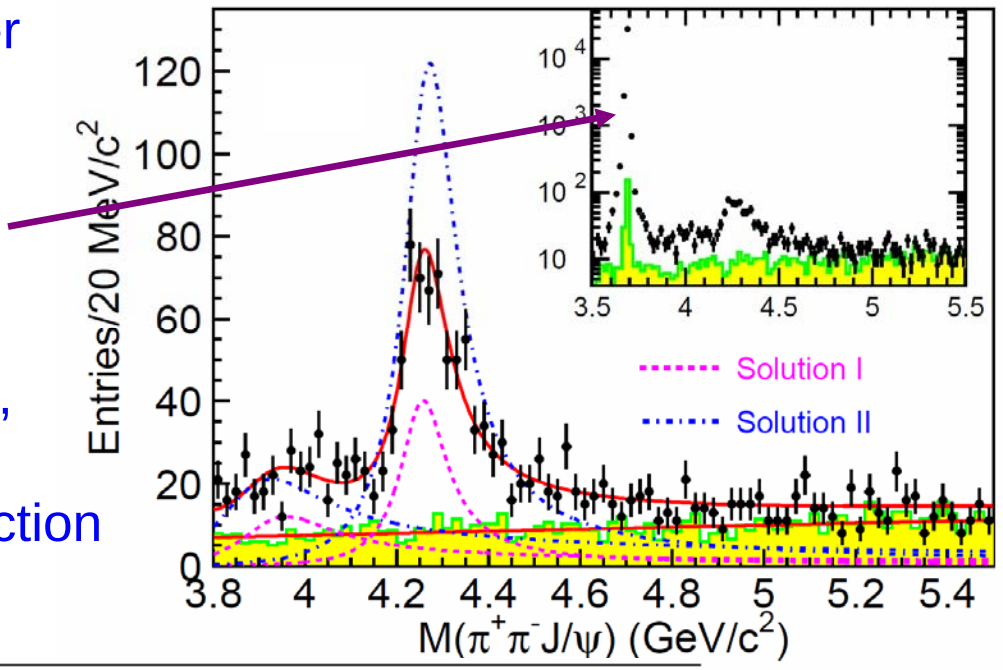
$$\Gamma_{Y(4260)} = (114^{+16}_{-15} \pm 7) MeV$$

- **Continuum contribution to cross section seems to be missing**

Updated Y(4260) results from Belle

Event selections are almost the same as in previous Belle published paper **PRL99, 182004 (2007)**

Lum: 967.02fb^{-1}

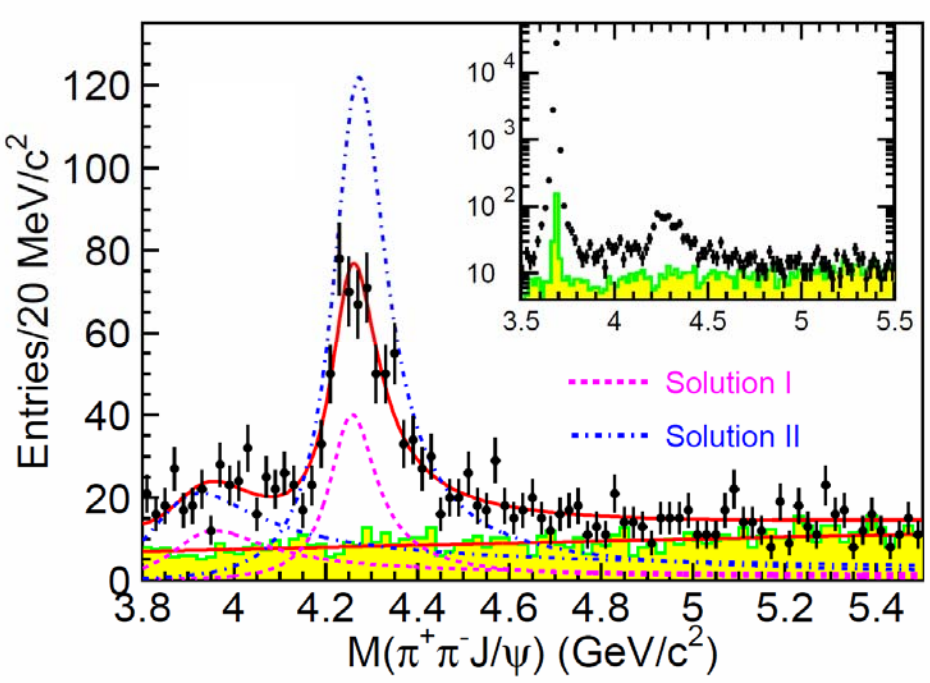


- Clean ψ(2S) signal events are obtained, purity>99%.
- Fit data with double Gaussian yields M(ψ(2S))=(3686.1$\pm$0.2)MeV, σ=4.8MeV
- We calculated ISR Ψ(2S) production cross section:

	e^+e^-	$\mu^+\mu^-$	QED
$\sigma(\Upsilon(4S))$	$(14.12 \pm 0.18 \pm 0.85)$ pb	$(15.09 \pm 0.11 \pm 0.79)$ pb	(14.25 ± 0.26) pb
$\sigma(\Upsilon(5S))$	$(13.79 \pm 0.44 \pm 0.83)$ pb	$(13.33 \pm 0.25 \pm 0.70)$ pb	(13.42 ± 0.25) pb
$\sigma(\Upsilon(2S))$	$(16.75 \pm 0.85 \pm 1.01)$ pb	$(16.63 \pm 0.54 \pm 0.87)$ pb	(16.03 ± 0.29) pb

Belle: arXiv:1304.0121

Two resonances fit



We still observed two resonances, Y(4008) and Y(4260) , which agrees with Belle's previous results.

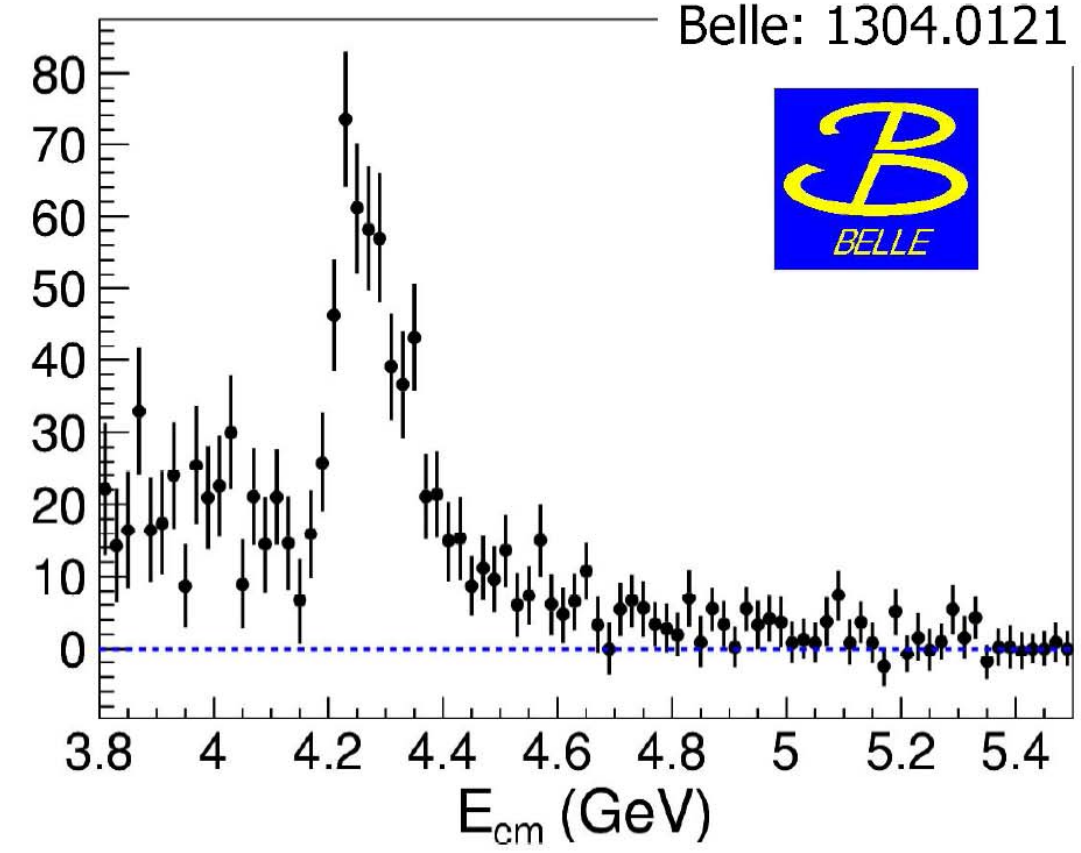
R_1=Y(4008)
R_2=Y(4260)

Parameters	Solution I	Solution II
$M(R_1)$	$3890.8 \pm 40.5 \pm 11.5$	
$\Gamma_{\rm tot}(R_1)$	$254.5 \pm 39.5 \pm 13.6$	
$\Gamma_{ee}\mathcal{B}(R_1 \to \pi^+\pi^- J/\psi)$	$(3.8 \pm 0.6 \pm 0.4)$	$(8.4 \pm 1.2 \pm 1.1)$
$M(R_2)$	$4258.6 \pm 8.3 \pm 12.1$	
$\Gamma_{\rm tot}(R_2)$	$134.1 \pm 16.4 \pm 5.5$	
$\Gamma_{ee}\mathcal{B}(R_2 \to \pi^+\pi^- J/\psi)$	$(6.4 \pm 0.8 \pm 0.6)$	$(20.5 \pm 1.4 \pm 2.0)$
ϕ	$59 \pm 17 \pm 11$	$-116 \pm 6 \pm 11$

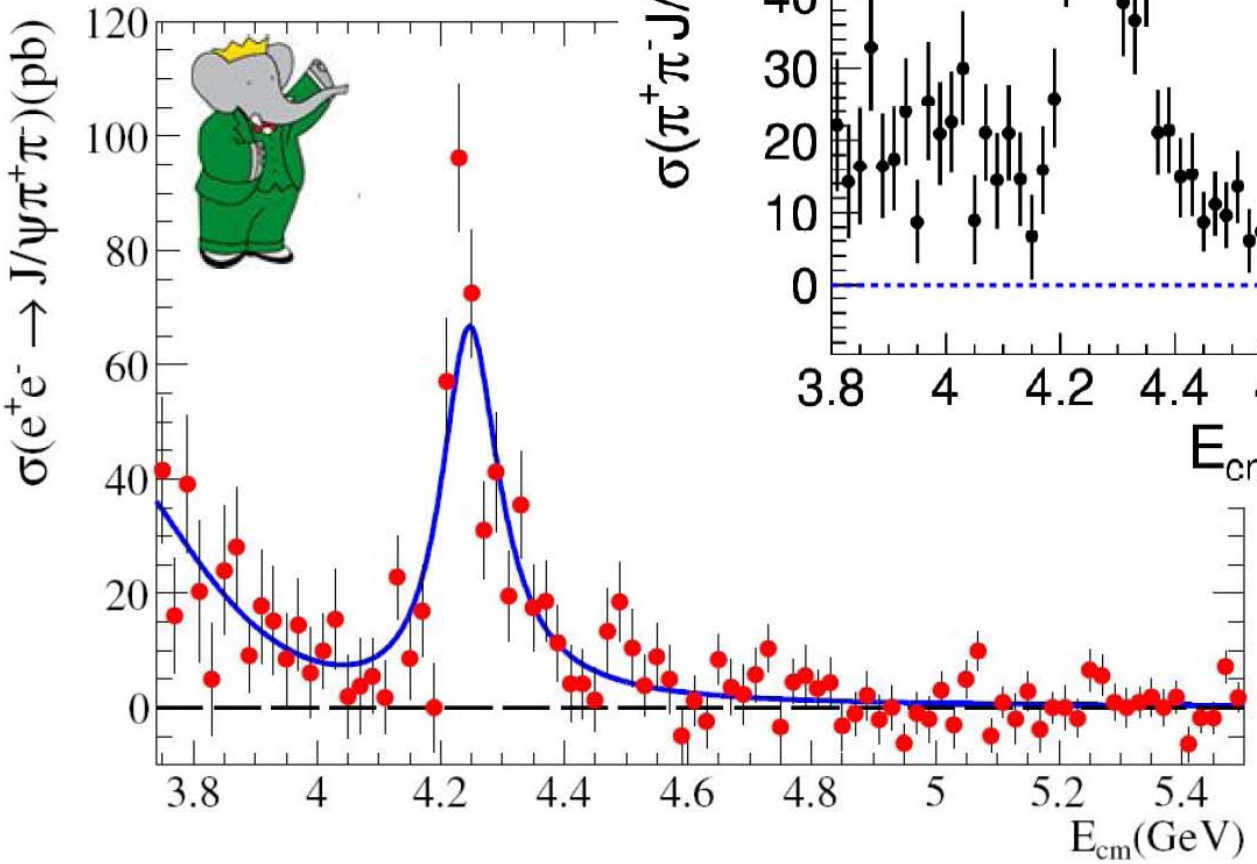
1. Fit with two coherent resonance $|BW_1+BW_2*\exp(i\phi)|^2$+bkg.
2. Mass of Y(4008) is smaller than 4008 MeV
3. Fit quality: χ^2/ndf=101/84, confidence level of 9.3%

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

Belle: 1304.0121



BaBar:
PRD86, 051102 (2012)

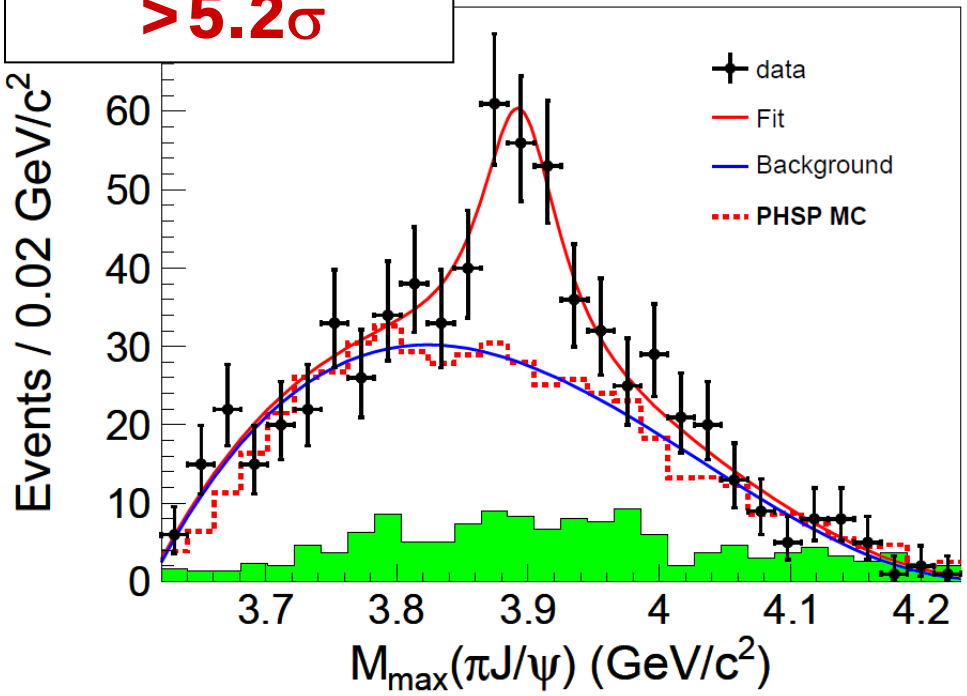


BESIII could be able to judge!

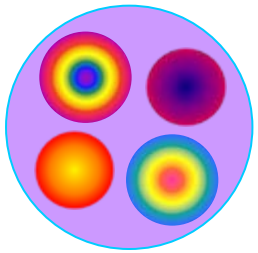
The Z(3895) signal

Significance >5.2σ

Belle: arXiv:1304.0121



- Couples to $c\bar{c}$
- Has electric charge
- At least 4-quarks
- What is its nature?



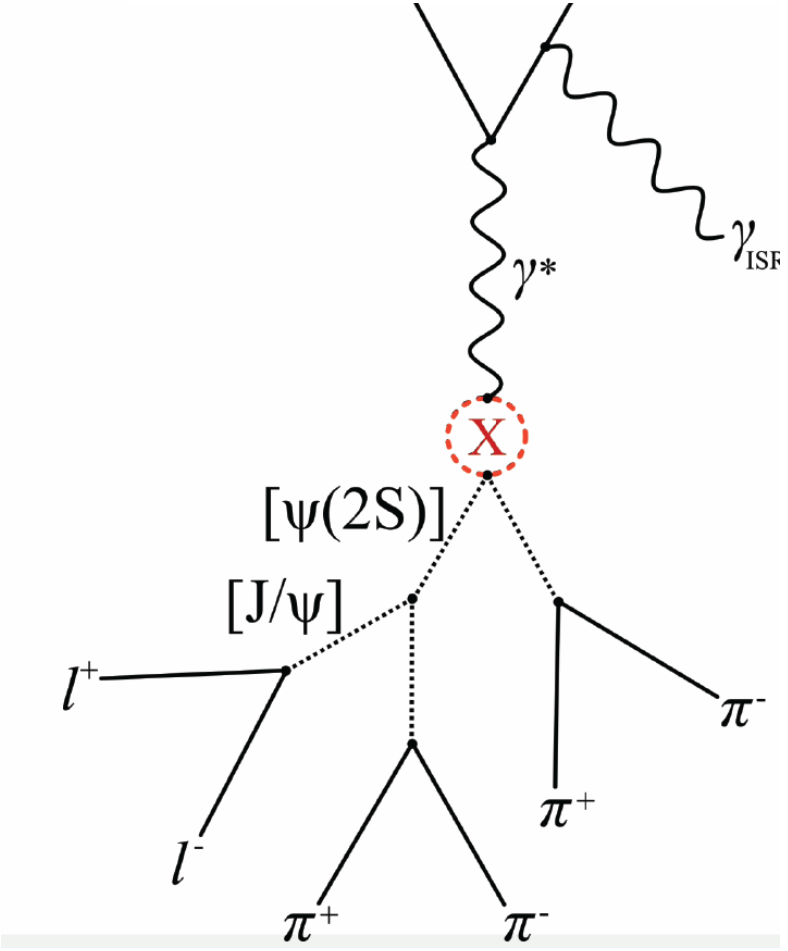
- S-wave Breit-Wigner convolved with a Gaussian (7.4 MeV); background: a cubic polynomial
- Mass = (3894.5±6.6±4.5) MeV
- Width = (63±24±26) MeV
- Fraction = (29.0±8.9)% (stat. error only)

- **Similar to Zb state observed in $\pi\Upsilon$(nS) and πh_b ?**
- **For details, please see Zhiqing's talk.**

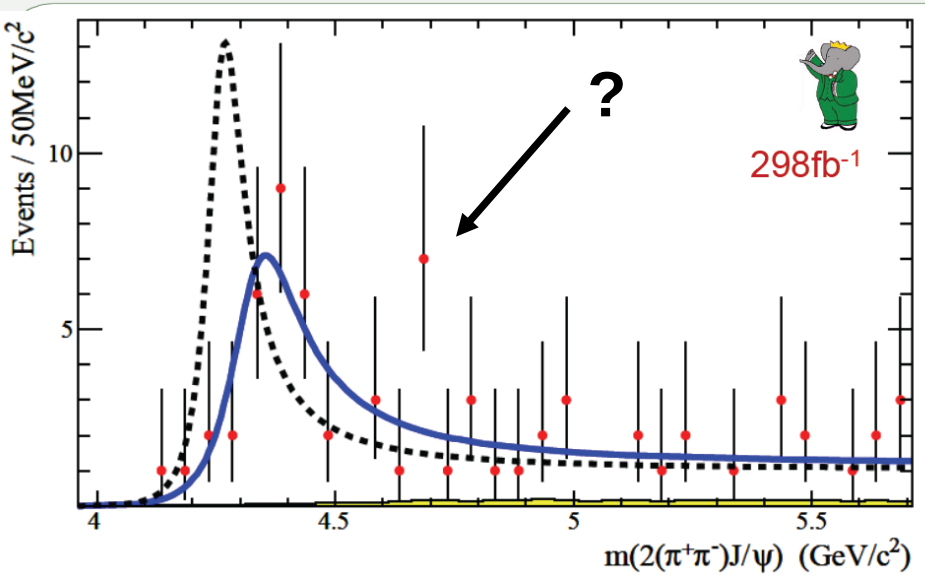
Y(4360), Y(4660)

ISR production in charmonium region

- Analogous to $\pi^+\pi^- J/\psi$ with $X \to \pi^+\pi^- \psi(2S)$
- Plausible access to other exotic states
- Main decay mode:
  - $e^+e^- \to \gamma_{ISR}\, X$
  - $X \to \pi^+\pi^- \psi(2S)$
  - $\psi(2S) \to \pi^+\pi^- J/\psi$
  - $J/\psi \to l^+l^-$
- Additional mode:
  - $e^+e^- \to \gamma_{ISR}\, X$
  - $X \to \pi^+\pi^- \psi(2S)$
  - $\psi(2S) \to l^+l^-$



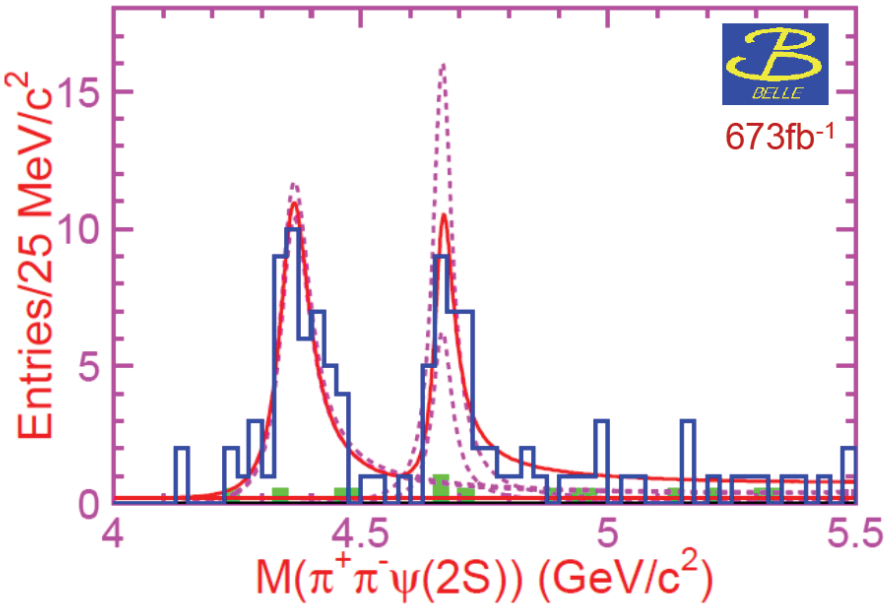
Previous Y(4360), Y(4660) results



BaBar: Y(4350) observation

- Search for Y(4260)
- Poor match to Y(4260) lineshape [dashed]
- Instead, Y(4325) observed
- PRL 98, 212001 (2007)

$$m_{Y(4325)} = (4324 \pm 24) MeV/c^2$$
$$\Gamma_{Y(4325)} = (172 \pm 33) MeV$$



Belle: Y(4350) + Y(4660)

- PRD 99, 182004 (2007)

$$m_{Y(4325)} = (4361 \pm 9 \pm 9) MeV/c^2$$
$$\Gamma_{Y(4325)} = (74 \pm 15 \pm 10) MeV$$
$$m_{Y(4660)} = (4664 \pm 11 \pm 5) MeV/c^2$$
$$\Gamma_{Y(4660)} = (48 \pm 15 \pm 3) MeV$$

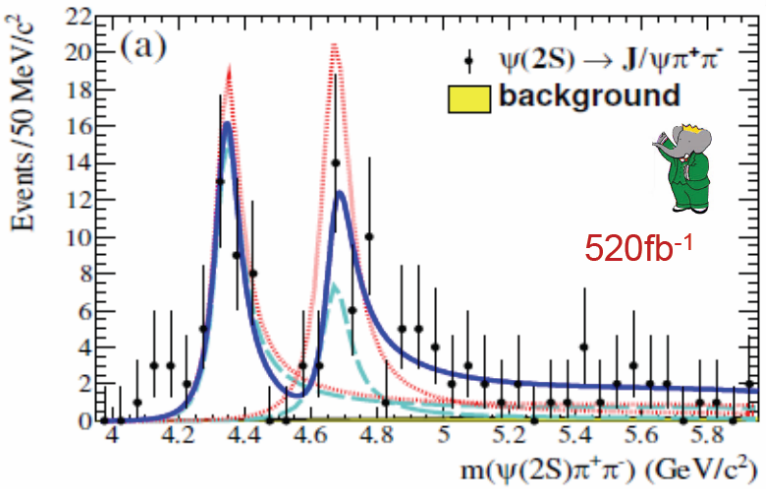
Updated Y(4360) and Y(4660) results from Babar

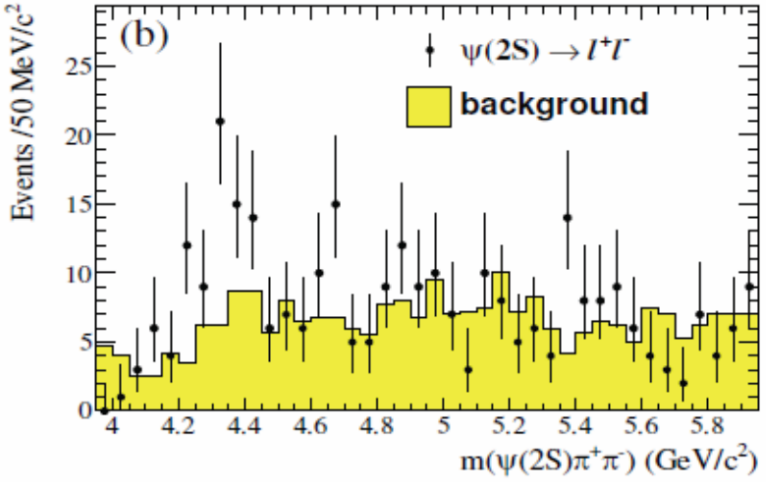
$\psi(2S) \to \pi^+\pi^- J/\psi$ [top]

- [added $\Upsilon(2,3S)$ runs]
- Very small background from $\psi(2S)$ sidebands
- **Y(4660) confirmed**
- Overlapping peaks have identical *PC*; interference terms do not cancel in mass projection
- Branching fraction measurement depends on interference assumption: **constructive** and **destructive**

$\psi(2S) \to l^+l^-$ [bottom]

- More data
- Much more background
- [supports Y(4660) but does not improve mass or width measurements]





Y(4360) and Y(4660) results from Babar and Belle

BaBar/Belle

- Y(4360) seen with similar mass/width to Belle confirmation
- Y(4660) **confirmed** with consistent mass/width
- Invariant mass spectra are very similar [top]
- Combined spectrum [bottom]: 1.2ab^{-1}! Huge datasets required to get substantially better results from ISR method

Belle 2007

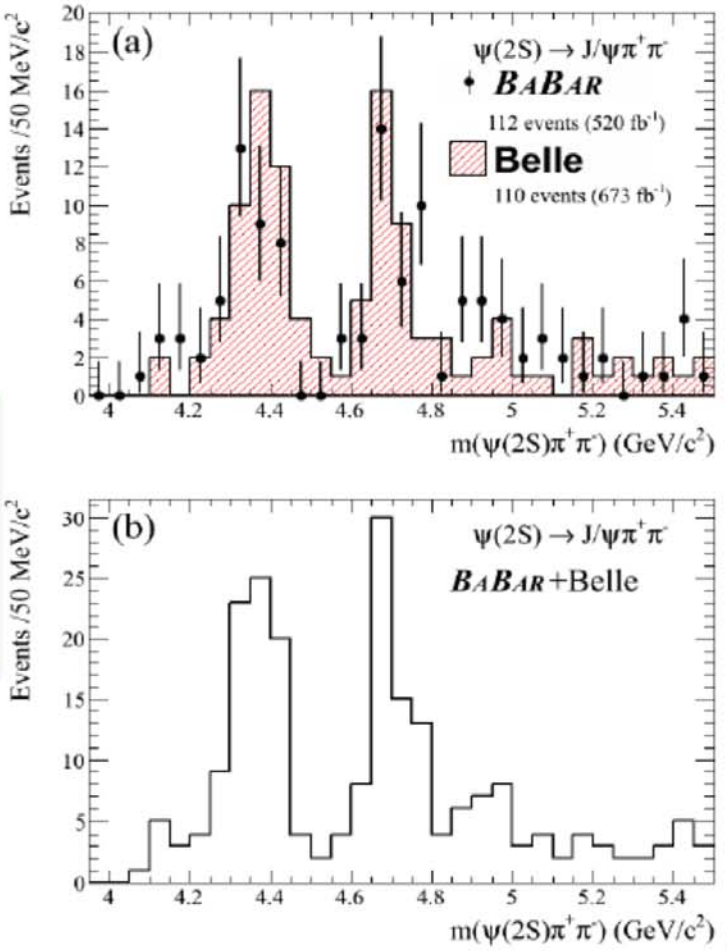
$$m_{Y(4325)} = (4361 \pm 9 \pm 9) MeV/c^2$$
$$\Gamma_{Y(4325)} = (74 \pm 15 \pm 10) MeV$$
$$m_{Y(4660)} = (4664 \pm 11 \pm 5) MeV/c^2$$
$$\Gamma_{Y(4660)} = (48 \pm 15 \pm 3) MeV$$

BaBar 2012

$$m_{Y(4325)} = (4340 \pm 16 \pm 9) MeV/c^2$$
$$\Gamma_{Y(4325)} = (94 \pm 32 \pm 13) MeV$$
$$m_{Y(4660)} = (4669 \pm 21 \pm 3) MeV/c^2$$
$$\Gamma_{Y(4660)} = (104 \pm 48 \pm 10) MeV$$

Y Decays

- Nothing conclusive from Y(4360)
- Y(4660) may have an $f_0(980)$ contribution

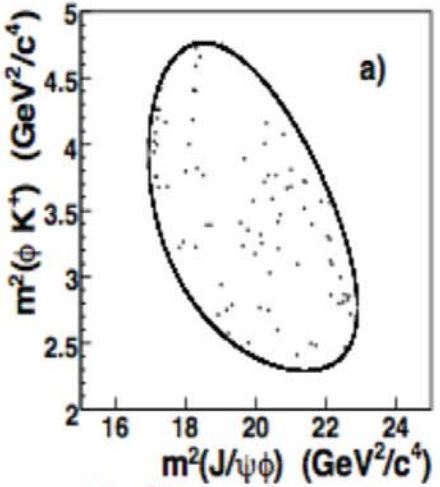


Updated results with full Belle data sample will be available soon !

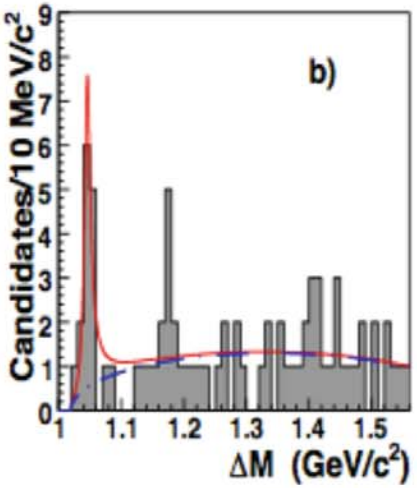
C=+ XY states

Y(4140)

Structures in J/ψφ Spectrum (CDF 09)



Dalitz plot



$\Delta M = m(\mu^+\mu^- K^+ K^-) - m(\mu^+\mu^-)$

2.7 fb^{-1}

PRL 102:242002, 2009

Purity ~80% in B$^+$ region

Nice φ shape

Near threshold peak, called Y(4140)

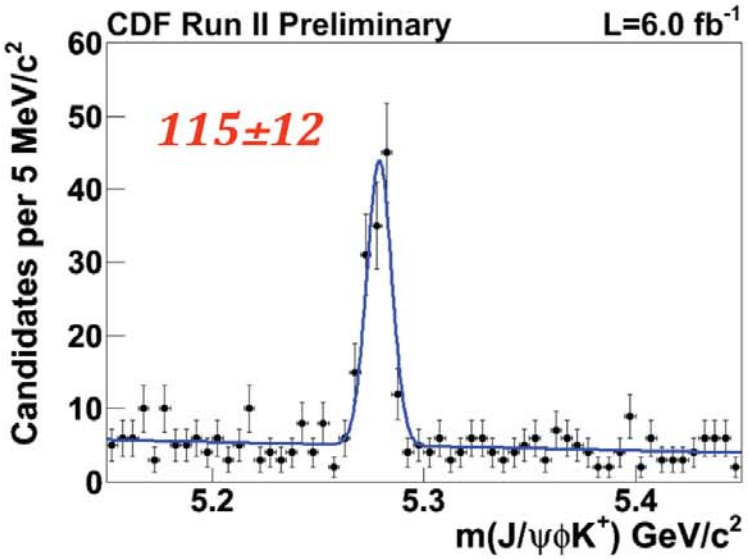
Significance: ~4σ, Yield =14±5

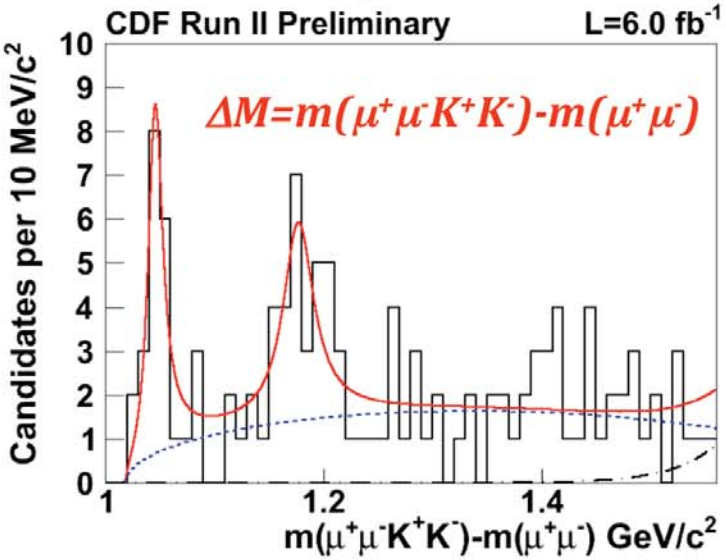
M= 4143.0 ± 2.9 (stat)± 1.2 (syst) MeV

Γ = $11.7\ ^{+8.3}_{-5.0}$ (stat) ± 3.7(syst) MeV

Not likely to be charmonium: high mass w/ narrow width

Structures in J/ψϕ Spectrum (CDF 10)





arXiv:1101.6058 [hep-ex]

$Yield_1$ = 19±6; >5σ

$Yield_2$ = 22±8; 3.1σ

$M_1 = 4143.4^{+2.9}_{-3.0}\,(stat) \pm 0.6\,(syst)$ MeV

$M_2 = 4277.4^{+8.4}_{-6.7}\,(stat) \pm 1.9\,(syst)$ MeV

$\Gamma_1 = 15.3^{+10.4}_{-6.1}\,(stat) \pm 2.5(syst)$ MeV

$\Gamma_2 = 32.3.7^{+21.9}_{-15.3}\,(stat) \pm 7.6(syst)$ MeV

χ^2/dof between old and new Δm is 7.2/3, p-value=6.5% w/ four regions

$$\frac{\mathcal{B}(B^+ \to Y(4140)K^+, Y(4140) \to J/\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} = 0.149 \pm 0.039(\text{stat}) \pm 0.034(\text{syst})$$

Y(4140) not significant at Belle

- Belle: B→J/ψϕK with 772M BB̲

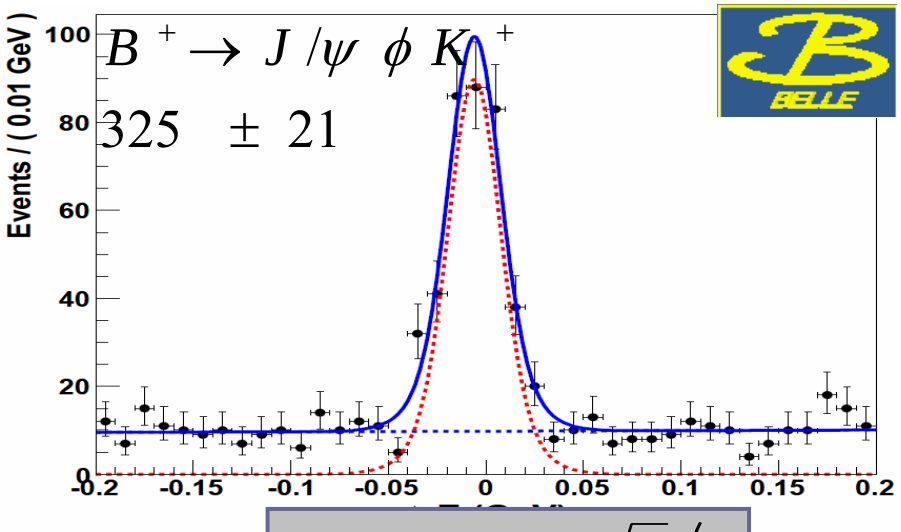
  M(J/ψϕ) fit with Y(4140) parameters fixed

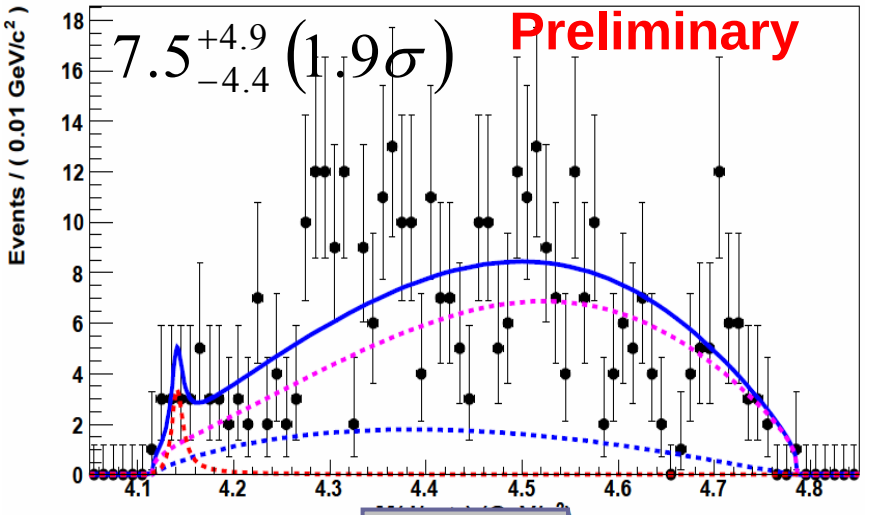
[but low effciency at J/ψϕ threshold]

$$Br\left(B^+ \to Y(4140)K^+, Y \to J/\psi\phi\right) < 6\times10^{-6}\ @\ 90\%\ C.L$$

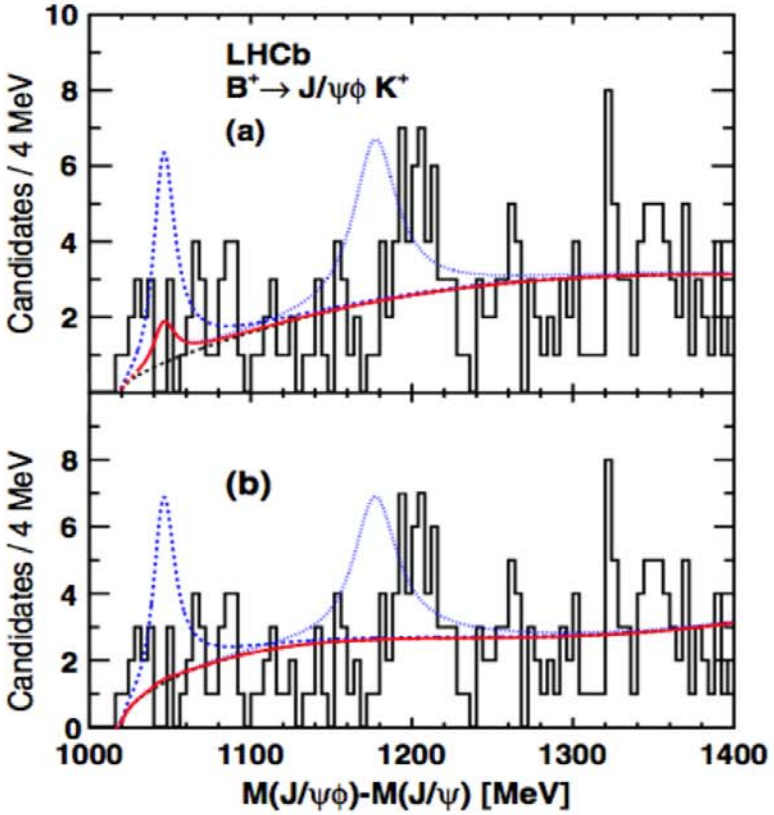
CDF result :

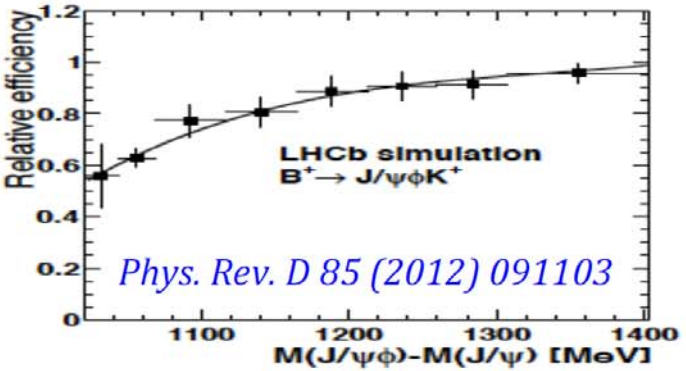
$$Br\left(B^+ \to Y(4140)K^+, Y \to J/\psi\phi\right) = \left(9.0 \pm 3.4 \pm 2.9\right)\times10^{-6}$$





LHCb: does not confirm





Phys. Rev. D 85 (2012) 091103

LHC_b confirms neither structure(s)

2.4σ disagreement with CDF measurement

@90% CL:

$$\frac{\mathcal{B}(B^+ \to X(4140)K^+) \times \mathcal{B}(X(4140) \to J/\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} < 0.07.$$

$$\frac{\mathcal{B}(B^+ \to X(4274)K^+) \times \mathcal{B}(X(4274) \to J/\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} < 0.08$$

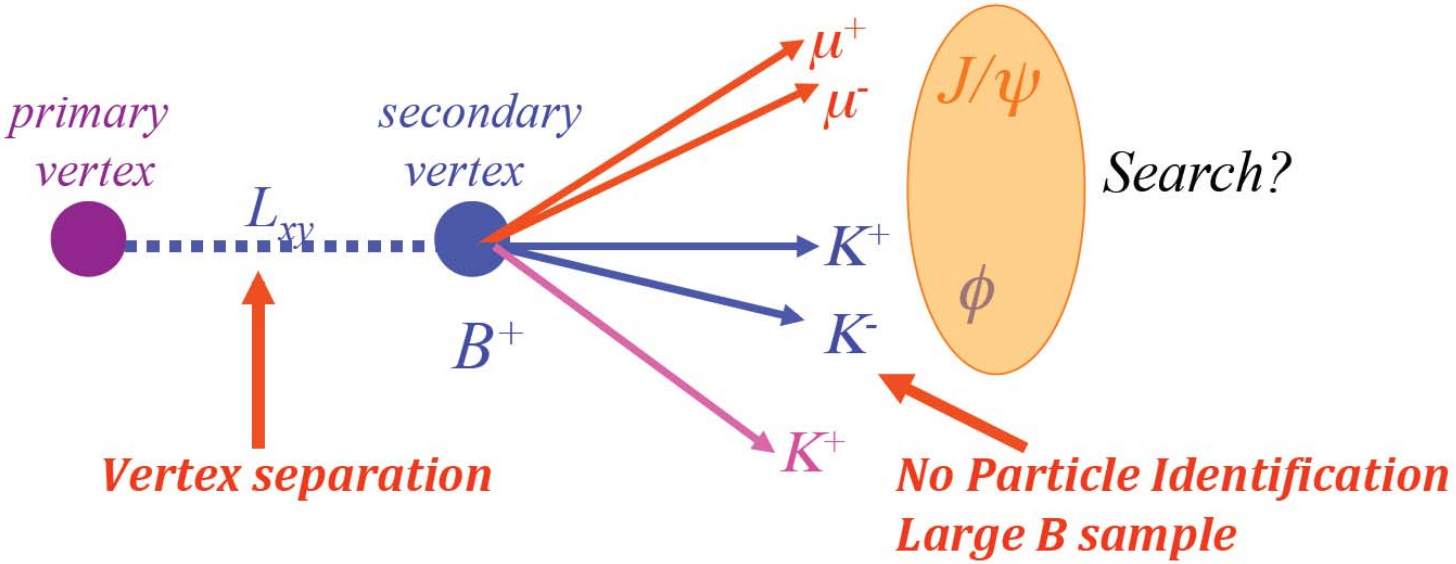
Need an independent result, CMS?

$J/\Psi\phi$ analysis strategy (CMS 2012)

- *I) Reconstruct B^+ as:*

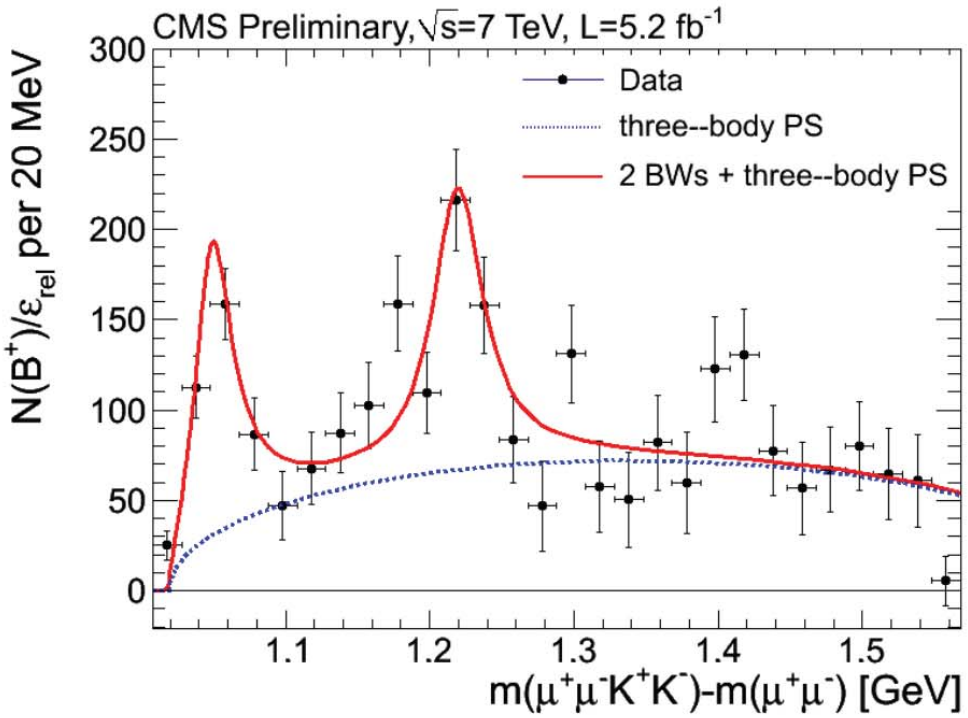
$$B^+ \rightarrow J/\psi\phi\, K^+$$
$$J/\psi \rightarrow \mu^+\mu^-$$
$$\phi \rightarrow K^+K^-$$

- *II) Search for structure in $J/\psi\phi$ mass spectrum inside B^+ mass window*



CMS Results on $J/\psi\phi$ Structures

- *The efficiency-corrected* $\Delta m = m(\mu^+\mu^-K^+K^-) - m(\mu^+\mu^-)$



Significance: >5σ for 1st peak
evidence for 2nd peak

	Mass (MeV)	Signal Yield
First Peak	1051.5 ± 2.0	355 ± 46
Second Peak	1220.0 ± 3.0	445 ± 83

m_1= 4148.2±2.0(stat.)±4.6 (syst.) MeV
m_2= 4316.7±3.0(stat.)±7.3 (syst.) MeV

- *CMS observed a* $J/\psi\phi$ *structure at 4148MeV with a significance greater than* 5σ *consistent with CDF results on Y(4140)*

- *CMS finds evidence for a second structure at ~4317MeV*

May we search for it at BESIII ?

Summary of Y(4140) Status

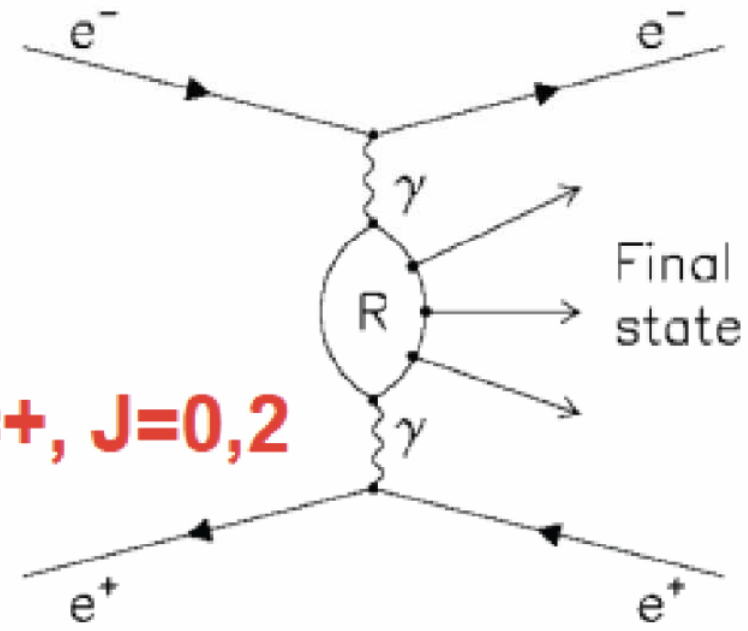
- *CDF positive report*
- *Belle cannot confirm or deny it*
- *LHCb did not confirm w/ 0.37 fb^{-1} data*

  (no official update, only unofficial plot w/ 1fb^{-1})
- *CMS confirms it w/ large statistics (7X LHCb)*
- *Apparent activity going on near the threshold*
- *ATLAS/CMS/LHCb can investigate its nature with more data*

- *A possible second structure, full amplitude analysis?*

X(3915)

Electron and positron beams emit (quasi-real) photons which interact and may form resonances



C=+, J=0,2

- Final state $e^{\pm}$ emitted along beam direction undetected
- allowed $J^{PC} = 0^{\pm+}, 2^{\pm+}$ (and $4^{\pm+}, 3^{++}, 5^{++}, \ldots$)
- low p_t with respect to beam axis

$\gamma\gamma \to J/\psi\omega$

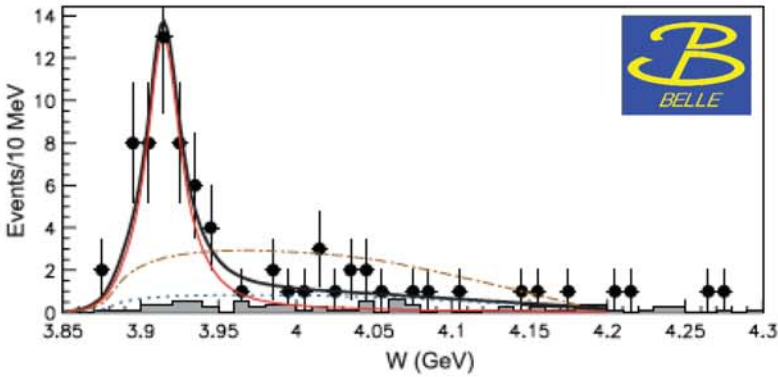
$X(3915)$ decaying to $J/\psi\omega$ observed by Belle in $\gamma\gamma$ PRL 104, 092001 (2010)

$$M = 3915 \pm 3 \pm 2 \text{ MeV}/c^2$$

$$\Gamma = 17 \pm 10 \pm 3 \text{ MeV}$$

$$\Gamma_{\gamma\gamma} \cdot \mathcal{B}(J\psi\omega) = 61 \pm 17 \pm 8 \text{ eV} \quad (J = 0)$$

$$\Gamma_{\gamma\gamma} \cdot \mathcal{B}(J\psi\omega) = 18 \pm 5 \pm 2 \text{ eV} \quad (J = 2)$$



but there are other resonances in the same final state or mass range

- $Y(3940)$ decaying to $J/\psi\omega$ has been observed in B decays

  PRL 94, 182002 (2005) PRL 101, 082001 (2008) PRD 82, 011101 (2010)

- $Z(3930)$ decaying to $D\bar{D}$ observed in $\gamma\gamma$

  PRL 96, 082003 (2006) PRD 81, 092003 (2010)

  angular distribution supports $J = 2$, identified with $\chi_{c2}(2P)$

Are they all the same or not?

Also, until recently, the assignment 2^{-+} for the X(3872) was not ruled out arXiv:1302.6269

Study of $X(3915) \to J/\psi\omega$ in $\gamma\gamma$ reactions at *BABAR*

$X(3915)$ confirmed by *BABAR* PRD 86, 072002 (2012)

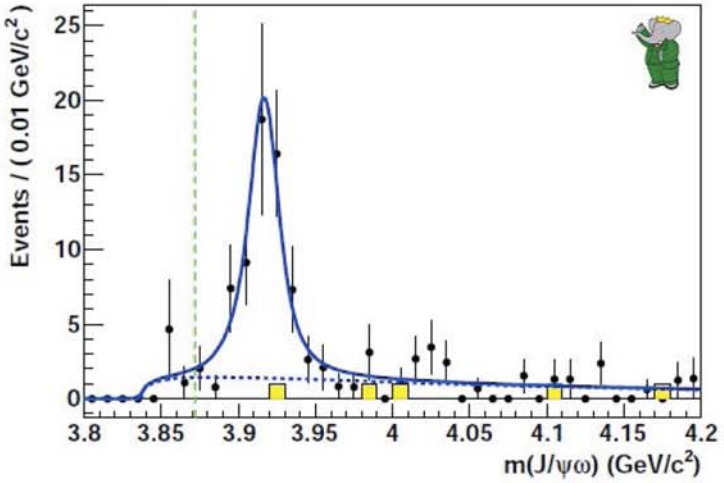
Resonance parameters in agreement with Belle:

$$M = 3919.4 \pm 2.2 \pm 1.6 \text{ MeV}/c^2$$

$$\Gamma = 13 \pm 6 \pm 3 \text{ MeV}$$

$$\Gamma_{\gamma\gamma} \cdot \mathcal{B}(J\psi\omega) = 52 \pm 10 \pm 3 \text{ eV} \quad (J = 0)$$

$$\Gamma_{\gamma\gamma} \cdot \mathcal{B}(J\psi\omega) = 10.5 \pm 1.9 \pm 0.6 \text{ eV} \quad (J = 2)$$



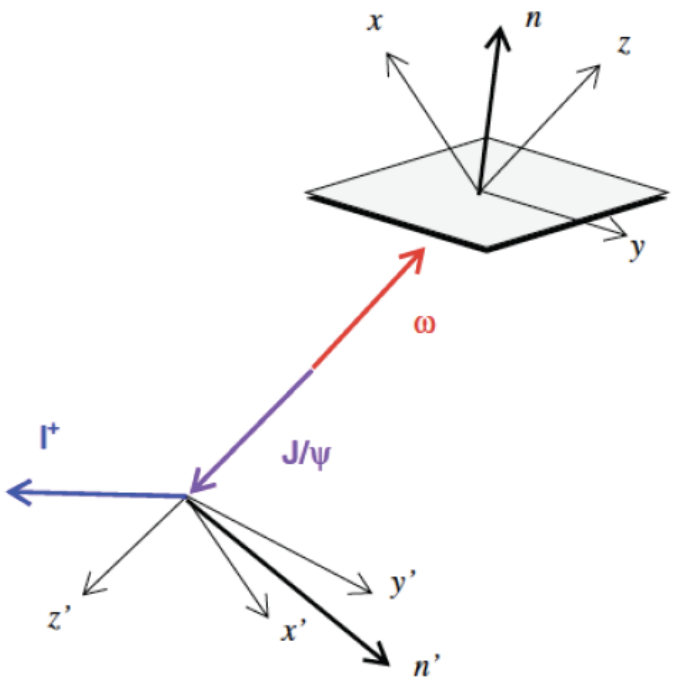
If $\Gamma_{\gamma\gamma} = \mathcal{O}(1 \text{ keV})$ (typical $c\bar{c}$), then $\mathcal{B}(J/\psi\omega) > (1-6)\%$

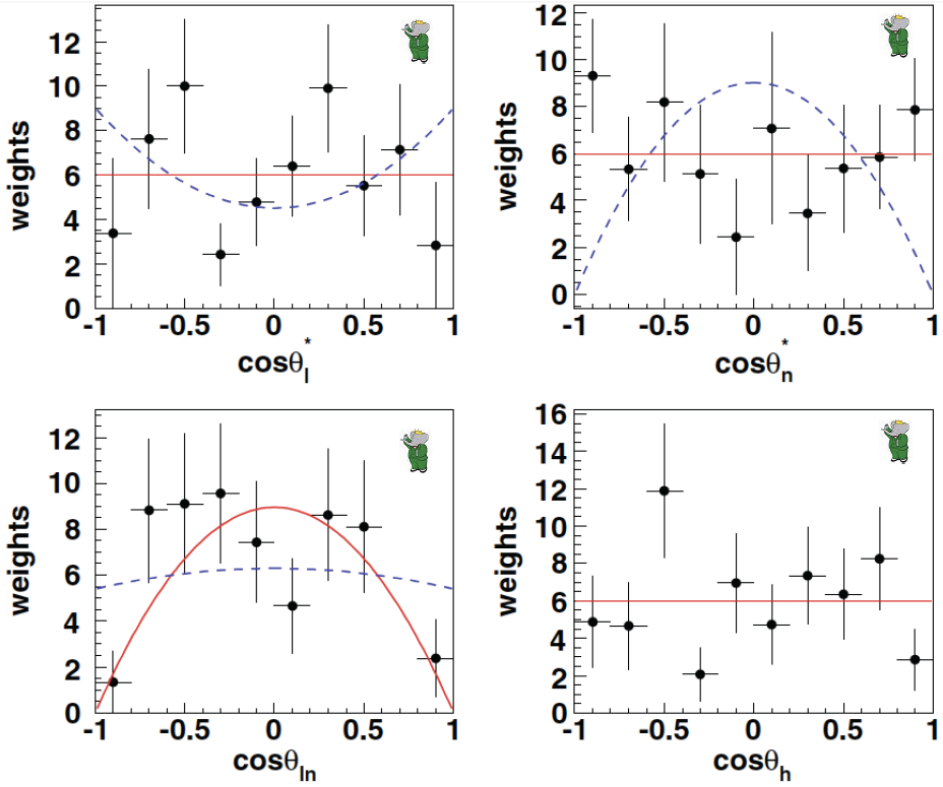
(Limit for $J = 2$ hypothesis of $X(3872)$: $\Gamma_{\gamma\gamma} \cdot \mathcal{B}(J\psi\omega) < 1.7$ eV)

Angular distribution for $\gamma\gamma \to J/\psi\omega$

Angular analysis follows J. L. Rosner, PRD 70, 094023 (2004)

Overall J=0 strongly preferred over J=2





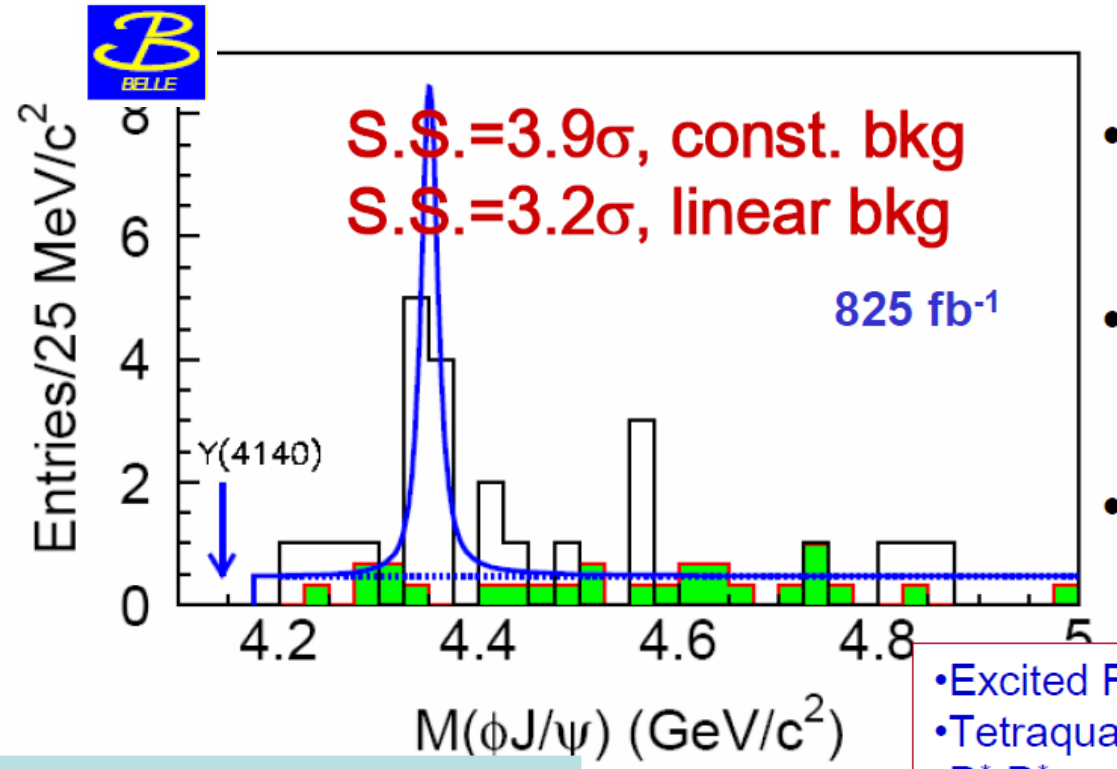
The angles are defined in three different center of mass frames: $J/\psi\omega$, J/ψ, and ω.

PRD 86, 072002 (2012)

$\chi_{c0}(2P)$ **candidate?**

May we search for it at BESIII ?

X(4350)



- M= $4350.6^{+4.6}_{-5.1} \pm 0.7$ MeV/c²
- Γ= $13.3^{+17.9}_{-9.1} \pm 4.1$ MeV/c²
- N (X(4350))= $8.8^{+4.2}_{-3.2}$

C.P.Shen, Belle Collab., PRL104,112004 (2010)

- Excited P-wave charmonium?
- Tetraquark? Fl. Stancu, arXiv: 0906.2485
- $D^*_s\overline{D^*_{s0}}$ molecule at 4.34±0.09 GeV? J.R.Zhang et al., arXiv:0905.4672

$J^P=0^+$: $\Gamma_{\gamma\gamma}Br(X(4350) \rightarrow \phi J/\psi) = 6.4^{+3.1}_{-2.3} \pm 1.1$ eV

$J^P=2^+$: $\Gamma_{\gamma\gamma}Br(X(4350) \rightarrow \phi J/\psi) = 1.5^{+0.7}_{-0.5} \pm 0.3$ eV

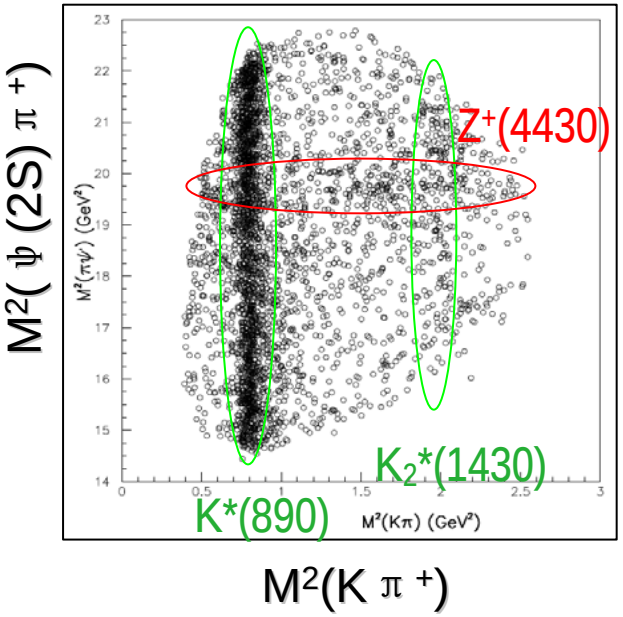
Some Z states

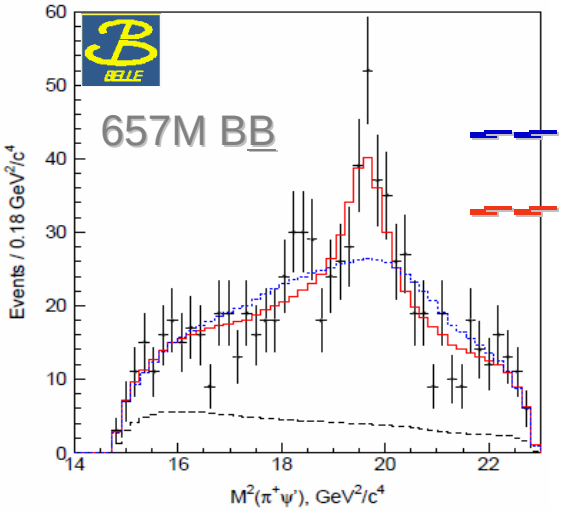
Belle observed $Z(4430)^{\pm}\to\psi(2S)\pi^{\pm}$

PRL100, 142001 (2008)

- Found in $\psi(2S)\pi^+$ from $B\to\psi(2S)\pi^+K$. Z parameters from fit to $M(\psi(2S)\pi^+)$
- Confirmed through Dalitz-plot analysis of $B\to\psi(2S)\pi^+K$
- $B\to\psi(2S)\pi^+K$ amplitude: coherent sum of Breit-Wigner contributions
- Models: all known $K^*\to K\pi^+$ resonances only

  all known $K^*\to K\pi^+$ and $Z^+\to\psi(2S)\pi^+$ ⇨ favored by data





M²(ψ (2S) π +) after K* veto

Significance: 6.4 σ

fit for model with K*'s only

fit for model with K*'s and Z

$$M = 4433\,^{+15\,+19}_{-12\,-13}\ \text{MeV}$$

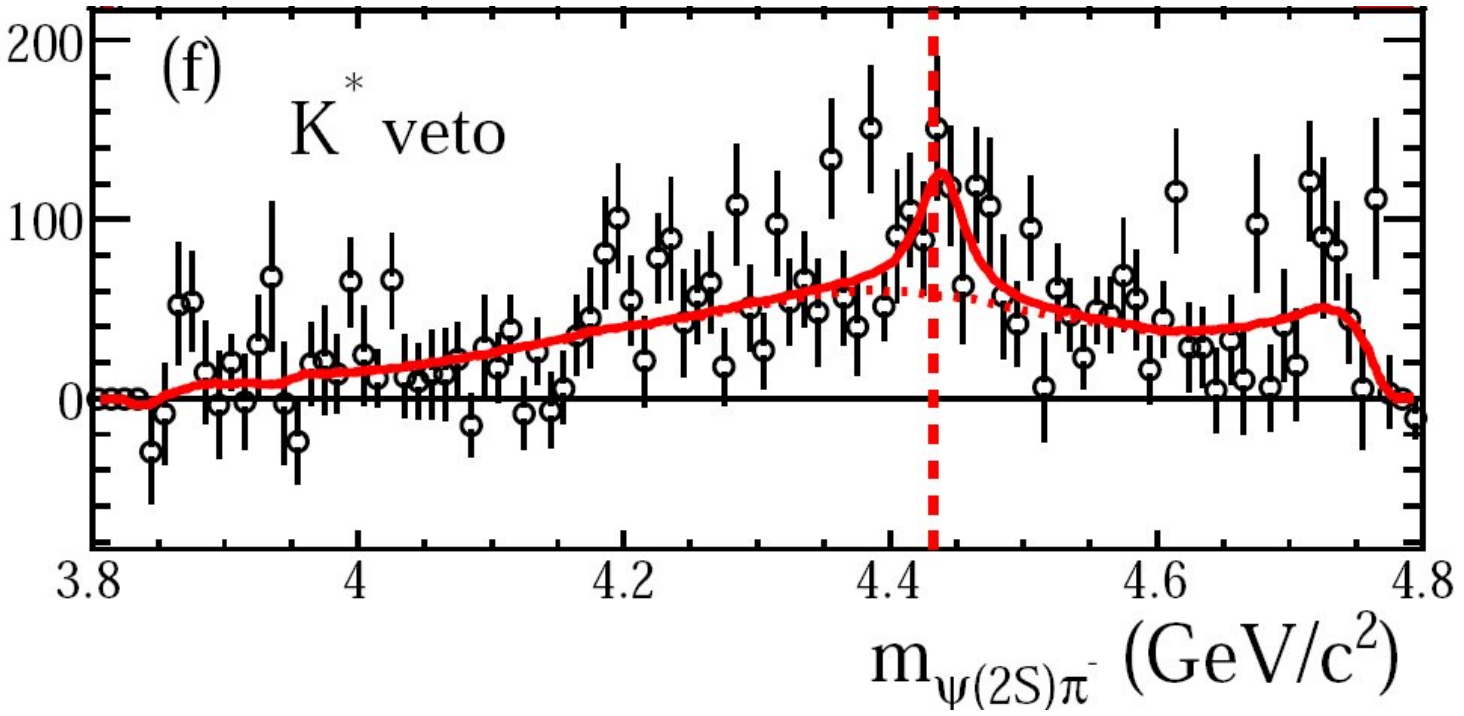
$$\Gamma = 107\,^{+86\,+74}_{-43\,-53}\ \text{MeV}$$

PRD80, 031104 (2009)

- [cu][$\underline{\text{cd}}$] tetraquark? neutral partner in $\psi'\pi^0$ expected
- $D^*\underline{D}_1(2420)$ molecule? should decay to $D^*\underline{D}^*\pi$

BaBar doesn't see a significant Z(4430)$^+$

PRD79, 112001 (2009)



"For the fit … equivalent to the Belle analysis…we obtain mass & width values that are consistent with theirs,… but only ~1.9σ from zero; fixing mass and width increases this to only ~3.1σ."

$$BF(B^0 \to Z^+ K) \times BF(Z^+ \to \psi(2S)\pi^+) < 3.1 \times 10^{-5}$$

Belle PRL: $(4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$

Measurement of $Z(4430)^+$ quantum numbers

NEW

★ Amplitude analysis in 4D phase:

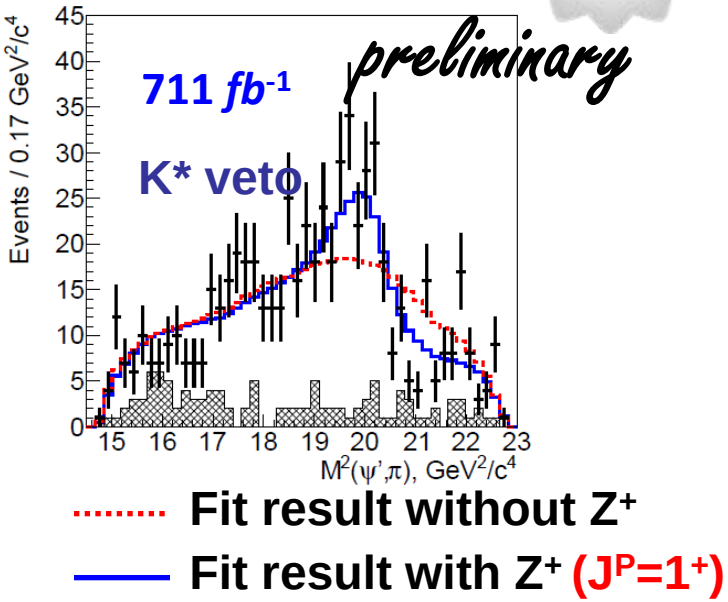
($M^2_{K\pi}$, $M^2_{\psi'\pi}$, $\phi_{\psi' K^*}$, $\theta_{\psi'}$).

$\phi_{\psi' K^*}$: angle between Ψ' and K* decay planes

$\theta_{\psi'}$: Ψ' helicity angle

TABLE I: Fit results: $Z^+ \to \psi'\pi^+$.

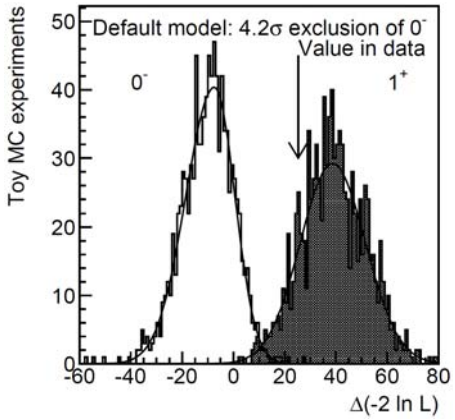
J^P	0^-	1^-	1^+	2^-	2^+
Mass, MeV	4470 ± 20	4482 ± 4	4500 ± 12	4545 ± 2	4367 ± 2
Width, MeV	139 ± 36	10.9 ± 0.3	126 ± 20	11.2 ± 0.6	9.1 ± 0.6
Significance	4.4σ	1.2σ	6.1σ	2.3σ	2.6σ



★ **The 1^+ hypothesis is preferred**

★ Exclusion levels are calculated from toy MC

★ 0^- is not excluded; significance of 1^+ over 0^- is 2.9σ. 1^-,2^- and 2^+ are excluded at levels of 5.5σ, 4.3σ,and 5.4σ



★ **We also calculated some Brs:**

$$\mathcal{B}(\bar{B}^0 \to \psi' K^- \pi^+) = (5.50 \pm 0.15 \pm 0.42) \times 10^{-4},$$

$$\mathcal{B}(\bar{B}^0 \to \psi' K^*(892)) = (4.93^{+0.30+1.40}_{-0.23-0.43}) \times 10^{-4},$$

$$\mathcal{B}(\bar{B}^0 \to Z(4430)^+ K^-) \times \mathcal{B}(Z(4430)^+ \to \psi'\pi^+) =$$

$$(3.4^{+1.1+0.4}_{-0.7-1.3}) \times 10^{-5} \quad \text{for } J^P = 1^+ \text{ or}$$

$$(1.4^{+0.8+0.6}_{-0.7-0.2}) \times 10^{-5} \quad \text{for } J^P = 0^-.$$

Belle observed Two $Z^{\pm}\to\chi_{c1}\pi^{\pm}$

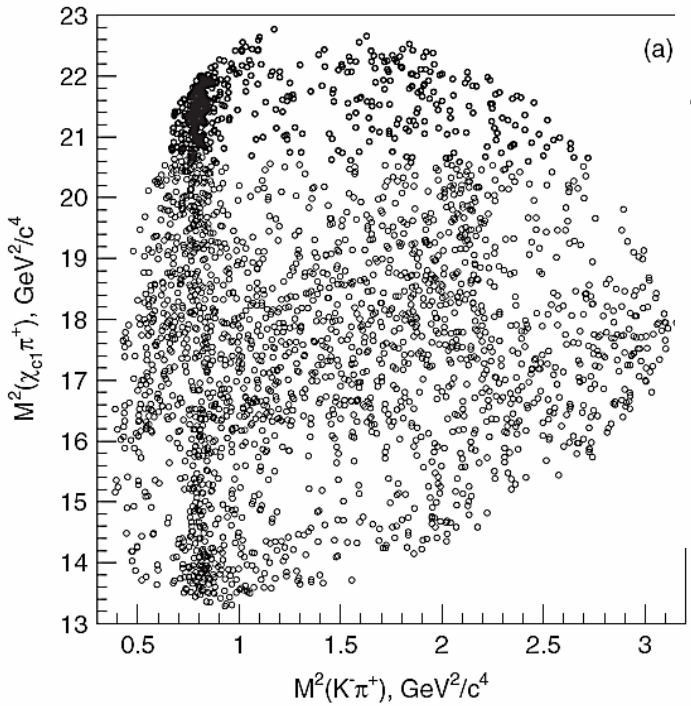
- Dalitz-plot analysis of $\underline{B^0}\to\chi_{c1}\pi^+K^-$ $\chi_{c1}\to J/\psi\gamma$ with 657M $B\underline{B}$
- Dalitz plot models: known $K^*\to K\pi$ only

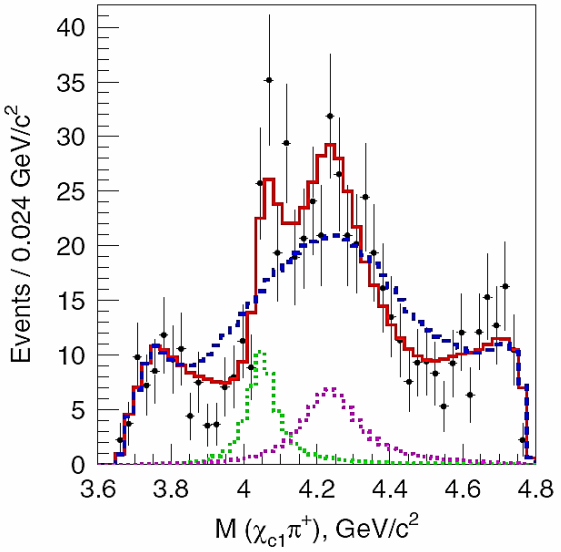
  K^*'s + one $Z\to\chi_{c1}\pi^{\pm}$

  K^*'s + two $Z^{\pm}$ states ⇨ favored by data

PRD 78, 072004 (2008)

Significance: 5.7σ





M($\chi_{c1}\pi^+$)
for $1<M^2(K^-\pi^+)<1.75\text{GeV}^2$

fit for model with K*'s

fit for double Z model

Z_1 contribution

Z_2 contribution

$$M_{Z_1} = 4051 \pm 14\,^{+20}_{-41}\ \text{MeV}$$

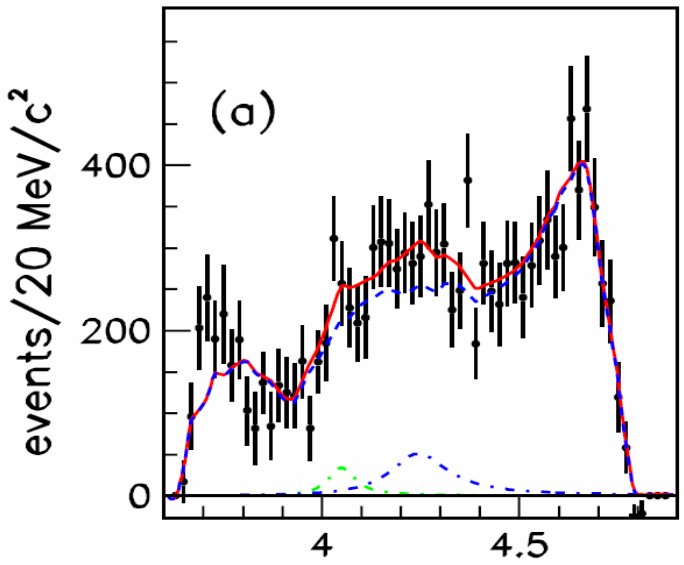
$$\Gamma_{Z_1} = 82\,^{+21\,+47}_{-17\,-22}\ \text{MeV}$$

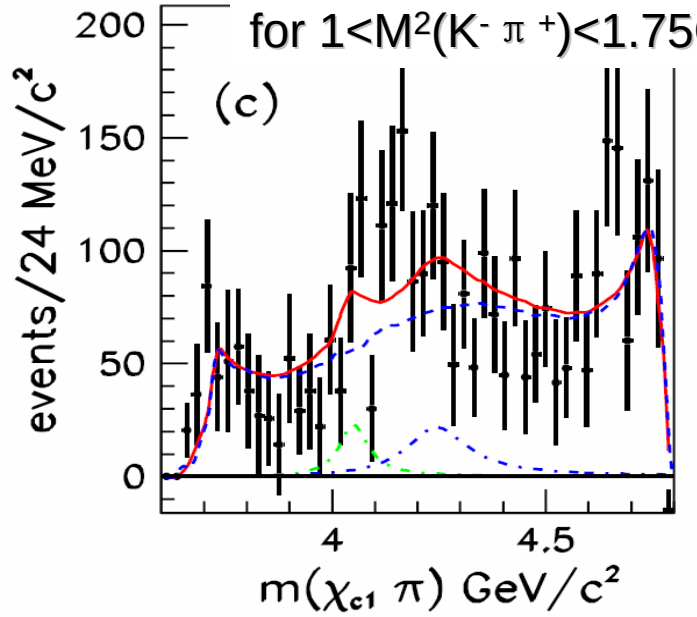
$$M_{Z_2} = 4248\,^{+44\,+180}_{-29\,-35}\ \text{MeV}$$

$$\Gamma_{Z_2} = 177\,^{+54\,+316}_{-39\,-61}\ \text{MeV}$$

BaBar doesn't see significant $Z^{\pm} \to \chi_{c1}\pi^{\pm}$

PRD85, 052003 (2012)





$$\mathcal{B}(\bar{B}^0 \to Z_1(4050)^+ K^-) \times \mathcal{B}(Z_1(4050)^+ \to \chi_{c1}\pi^+) < 1.8 \times 10^{-5},$$

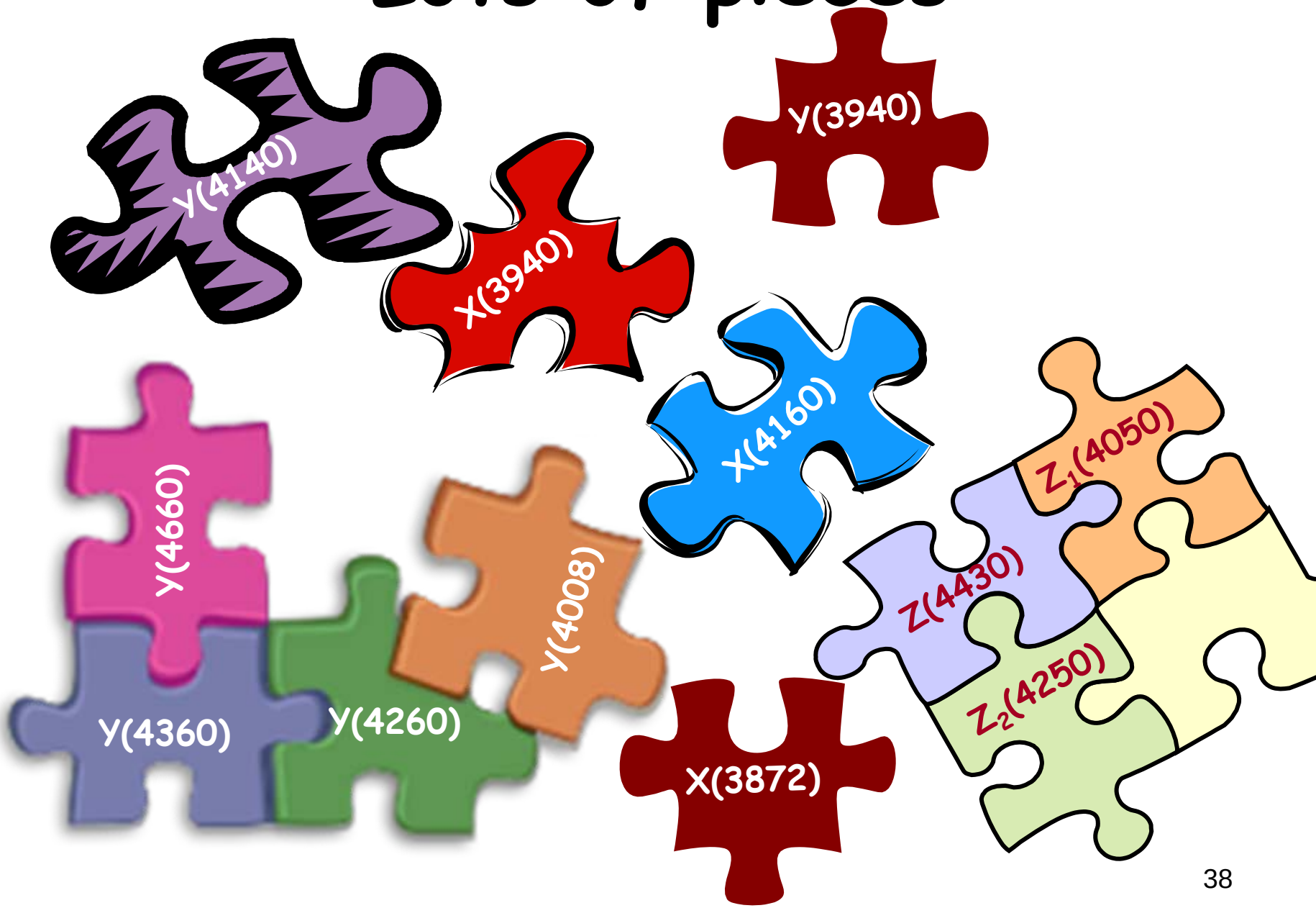
Belle: $(3.0^{+1.5}_{-0.8}{}^{+3.7}_{-1.6})\times10^{-5}$

$$\mathcal{B}(\bar{B}^0 \to Z_2(4250)^+ K^-) \times \mathcal{B}(Z_2(4250)^+ \to \chi_{c1}\pi^+) < 4.0 \times 10^{-5},$$

Belle: $(4.0^{+2.3}_{-0.9}{}^{+19.7}_{-0.5})\times10^{-5}$

"We find that it is possible to obtain a good description of our data without the need for additional resonances in the $\chi_{c1}\pi$ system."

Lots of pieces



Summary

- Here I just review some latest updated XYZ experimental results.
- Some XYZ states have been confirmed, some are still need further studies to confirm or deny them.
- Some quantum numbers of some states are still need to be determined by PWA or angular distributions with more data
- What can we do with more BESIII data at >4GeV?
- What can we do with current full of Belle data ? And further BelleII data ?