Charmonium-like states review

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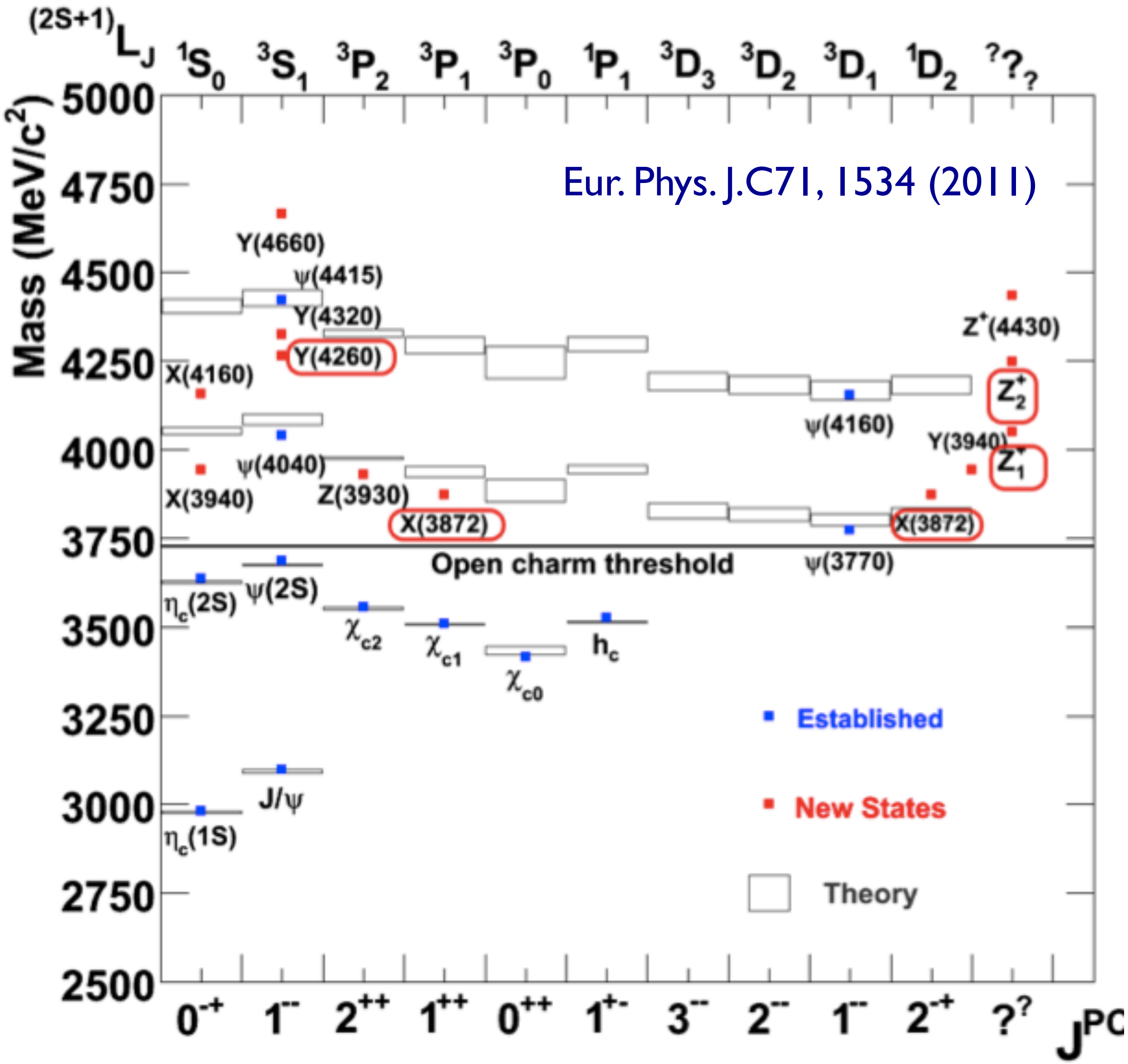
from the BaBar collaboration

Outline

- Introduction
- charmonium like states in $\gamma\gamma$ interaction
  - $\gamma\gamma \rightarrow J/\psi\ \omega$
  - $\gamma\gamma \rightarrow \eta_c\ \pi^+\pi^-$
- charged charmonia (Z^+, Z_1^+, Z_2^+)
- states with strange content: $J/\psi\ \phi$.
- $\psi(1S, 2S)\ \pi^+\pi^-$ spectrum after initial state radiation

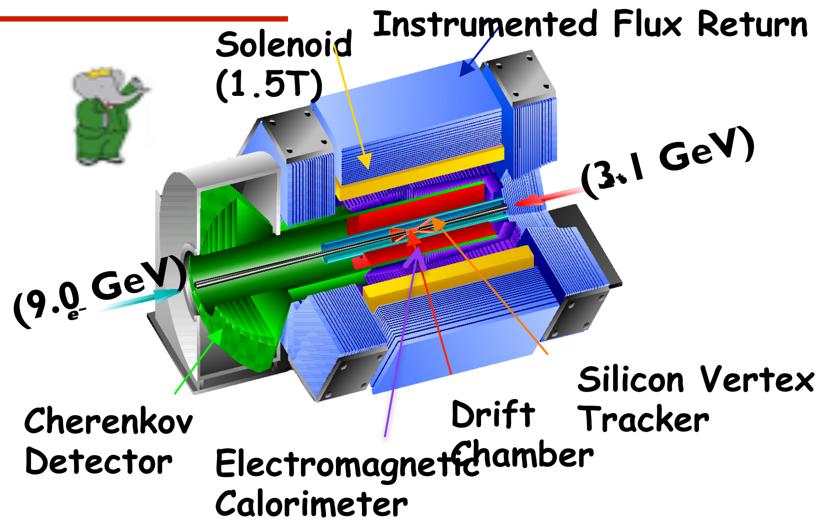
Motivations

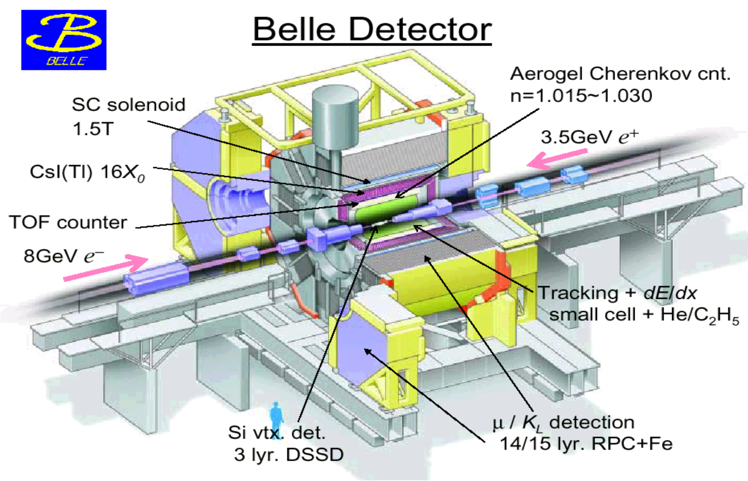
The charmonium spectrum



- Below the $D\bar{D}$ threshold all the states of the charmonium spectrum are established; their measured decay properties are in good agreement with theory.
- Many unexpected states above the $D\bar{D}$ threshold. Several exotic hypotheses on their nature: e.g. tetraquarks, hadronic molecules, hybrids, glueballs, hadro-quarkonia.
- To identify exotics:
  - Measure J^{PC} that is forbidden for charmonium: 0^{+-}, 1^{-+}, 2^{+-}
  - Observe a narrow width for a state above $D\bar{D}$ threshold
  - Observe a $c\bar{c}$-like state with charge and/or strangeness
- But also threshold effects, coupled channels, artifacts…

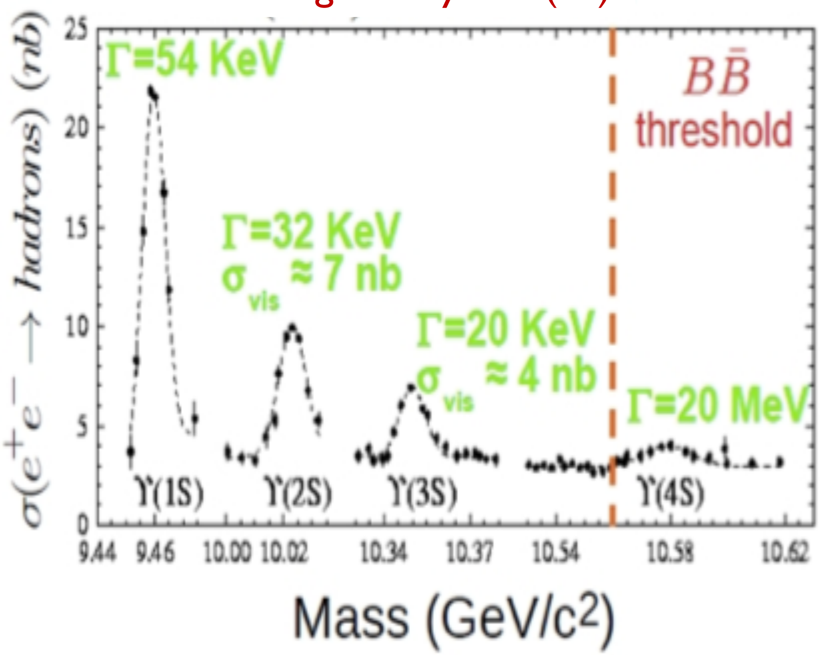
Charmonium like states at B factories





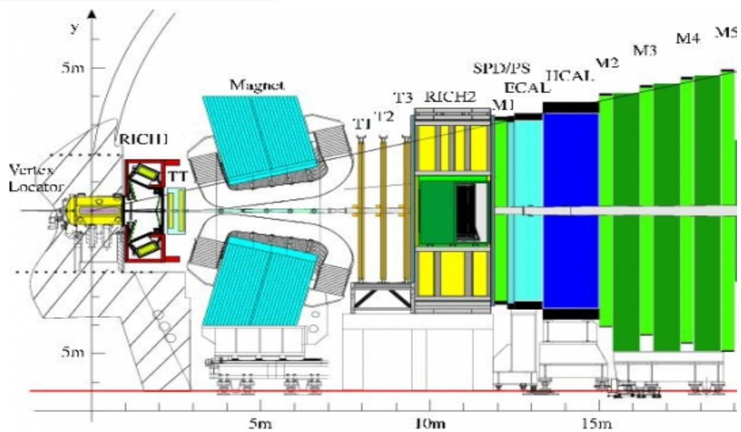
- Large samples of Υ(nS) and B mesons
- also very large samples of charm mesons and chamonium
  - $\sigma(e^+e^-\rightarrow c\bar{c}) \sim 1.3$nb
  - in b→c decays
  - in ISR production
  - also double charmonium and $\gamma\gamma$
- Low multiplicity, can reconstruct complete events.

running mostly at Υ(nS)



	BELLE	BaBar
Υ(5S)	121 fb^{-1}	
Υ(4S)	711 fb^{-1}	433 fb^{-1}
Υ(3S)	3.0 fb^{-1}	30 fb^{-1}
Υ(2S)	24 fb^{-1}	14 fb^{-1}
Υ(1S)	5.7 fb-^{1}	
Off-res	87 fb^{-1}	54 fb^{-1}
Scan	68fb^{-1}	
Total	1020fb^{-1}	531fb^{-1}

Charmonium like states outside B-factories



LHCb

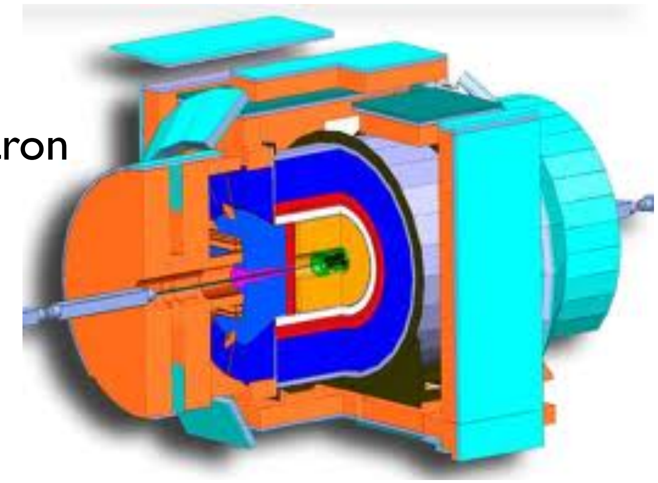
Dedicated detectors for B physics
low p_T regime

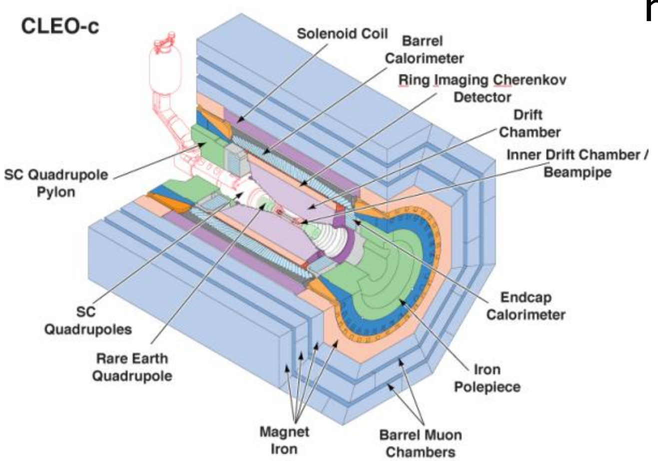
Low or moderate luminosity and pile-up
wrt other LHC experiments

Exclusive final states in high multiplicity environment

CDF

General purpose detector at Tevatron
high p_T regime

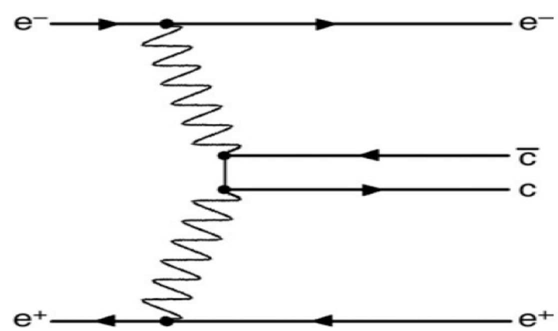




CLEO-c

at the Cornell Electron Storage Ring (CESR)
Experiment dedicated to charm physics

and more…



charmonium like states in γγ interaction

$\gamma\gamma \longrightarrow J/\psi\ \omega$

$\gamma\gamma \longrightarrow \eta_c\ \pi^+\pi^-$

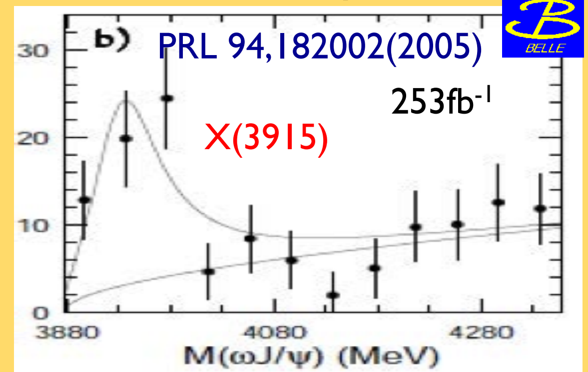
γγ —> J/ψ ω motivation (I)

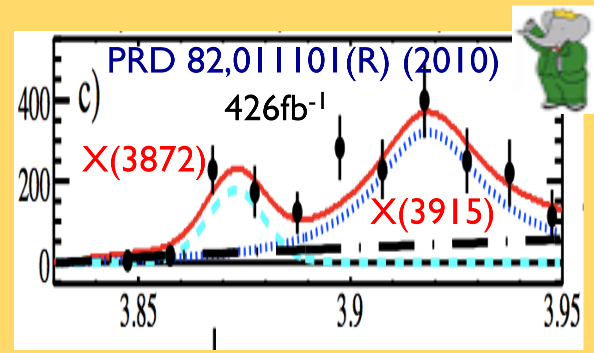
The X(3915)

- The X(3915) was seen both by Belle and BaBar in $B \to X(3915)K$, with $X(3915) \to J/\psi\ \omega$
- Belle observed also the X(3915) in $\gamma\gamma \to X(3915) \to J/\psi\ \omega$
- Interpretation of X(3915) as the $\chi_{c0}(2P)$ or $\chi_{c2}(2P)$ state has been suggested.
  T. Branz et al., Phys. Rev. D 83, 114015 (2011)
- $\Gamma_{\gamma\gamma}(X(3915))\mathcal{B}(X(3915) \to \omega J/\psi)$ reported by Belle is unexpectedly large compared to other excited charmonia.
- Molecular interpretation has also been suggested

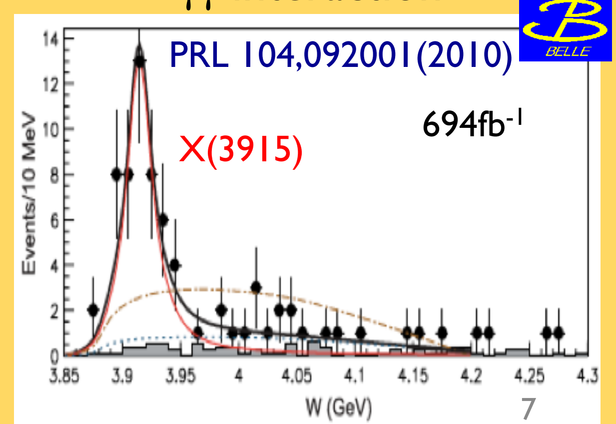
X. Liu et al., Eur. Phys. Jour. C 61, 411 (2009)
T. Branz et al., Phys. Rev. D 80, 054019 (2009)
W. H. Liang et al., Eur. Phys. Jour. A 44, 479 (2010)

B decays





γγ interaction

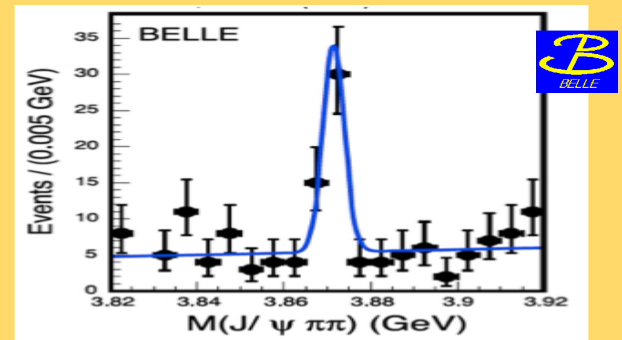


γγ —> J/ψ ω motivation (II)

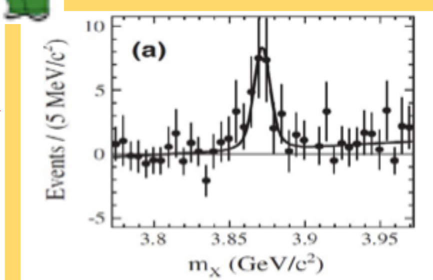
The X(3872)

- The X(3872) was discovered in B decays by Belle experiment in 2003.
- The observation of its decay into $J/\psi\ \gamma$ ensures that this particle has positive C-parity.
- The possible X(3872) quantum numbers could be $J^{PC} = 1^{++}$ or $J^{PC} = 2^{-+}$.
- The decay $X(3872) \rightarrow J/\psi\ \omega$ was seen in B decays both by Belle and BaBar.
- $\gamma\ \gamma \rightarrow X(3872)$ would imply $J^{PC} = 2^{-+}$ and it's not seen in Belle's spectrum.

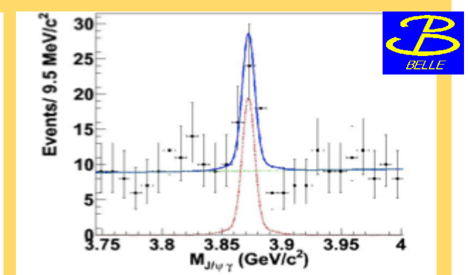
PRL 91 (2003) 262001



PRL 102, 132001 (2009)



PRL 107, 091803 (2011)

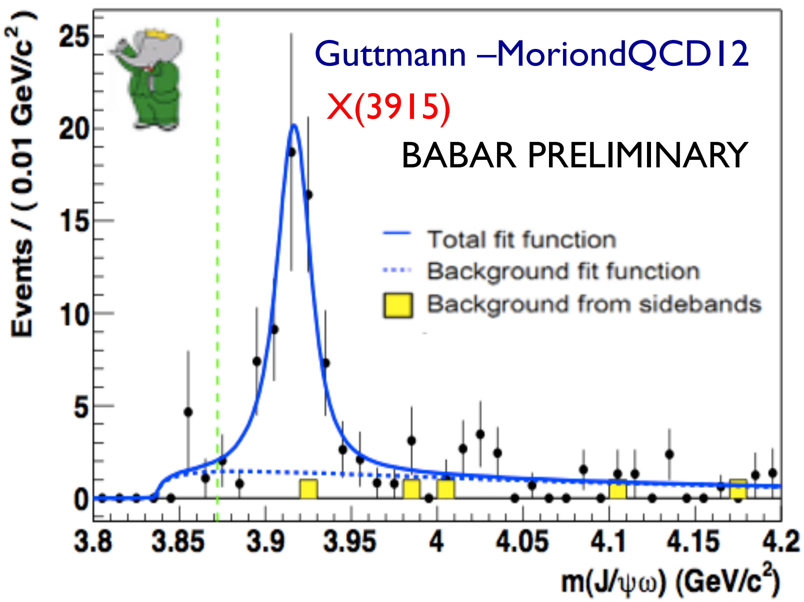


CDF PRL 98,132002

hypothesis	3D χ^2 / 11 d.o.f.	χ^2 prob.
1^{++}	13.2	27.8%
2^{-+}	13.6	25.8%
1^{--}	35.1	0.02%
2^{+-}	38.9	$5.5{\cdot}10^{-5}$
1^{+-}	39.8	$3.8{\cdot}10^{-5}$
2^{--}	39.8	$3.8{\cdot}10^{-5}$
3^{+-}	39.8	$3.8{\cdot}10^{-5}$
3^{--}	41.0	$2.4{\cdot}10^{-5}$
2^{++}	43.0	$1.1{\cdot}10^{-5}$
1^{-+}	45.4	$4.1{\cdot}10^{-6}$
0^{-+}	103.6	$3.5{\cdot}10^{-17}$
0^{+-}	129.2	$\leq 1{\cdot}10^{-20}$
0^{++}	163.1	$\leq 1{\cdot}10^{-20}$

γγ —> J/ψ ω: new BaBar results

- BaBar with 520 fb^{-1} collected at the ϒ (nS) sample (n = 2,3,4) confirmed the evidence of the X(3915) in $\gamma\gamma \rightarrow$ X(3915) $\rightarrow$ J/$\psi\,\omega$
- Good agreement with Belle's results



	BABAR	Belle*
Mass (MeV/c^2)	$3919.4 \pm 2.2 \pm 1.6$	$3915 \pm 3 \pm 2$
Width (MeV)	$13 \pm 6 \pm 3$	$17 \pm 10 \pm 3$
$\Gamma_{\gamma\gamma} \times \mathcal{B}$ (J=0) (eV)	$52 \pm 10 \pm 3$	$61 \pm 17 \pm 8$
$\Gamma_{\gamma\gamma} \times \mathcal{B}$ (J=2) (eV)	$10.5 \pm 1.9 \pm 0.6$	$18 \pm 5 \pm 2$

*Belle: PRL 104, 092001 (2010)

If $\Gamma_{\gamma\gamma} = \mathcal{O}(1\text{ keV})$ (typical $c\bar{c}$),

then $\mathcal{B}(J/\psi\omega) > (1-6)\%$

which is relatively large compared to charmonium model predictions

No evidence of the X(3872), limit for J=2 hypothesis

$\Gamma_{\gamma\gamma}(X(3872)) X B(X(3872) \rightarrow J/\psi\omega)(J=2) < 1.7$ eV

$\gamma\gamma \rightarrow \eta_c \pi^+\pi^-$ motivation

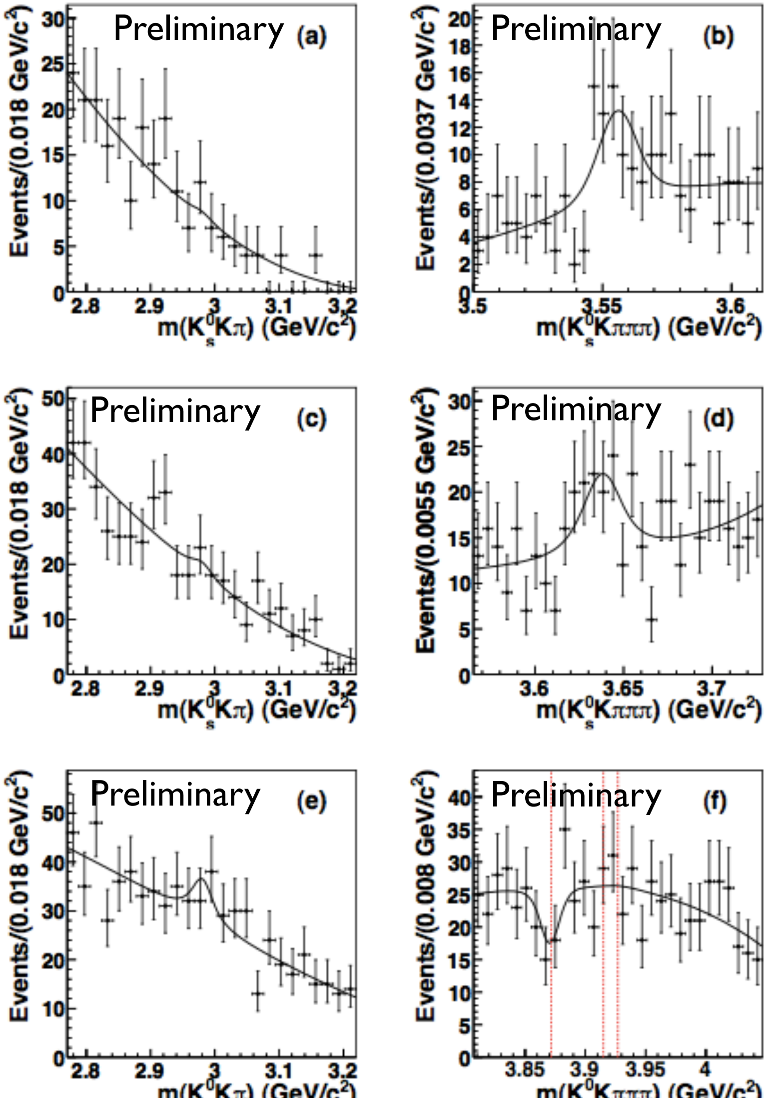
- BaBar looked at the process $\gamma\gamma \rightarrow X \rightarrow \eta_c(1S)\pi^+\pi^-$ where X stands for one of the resonances $\chi_{c2}(1P)$, $\eta_c(2S)$, X(3872), X(3915) or $\chi_{c2}(2P)$.
  $\eta_c(1S) \rightarrow K_s^0 K^\pm \pi^\mp$; $K_s^0 \rightarrow \pi^+\pi^-$

- Prediction for $B(\eta_c(2S) \rightarrow \eta_c(1S)\pi^+\pi^-)$ ~2.2% obtained from $\Gamma(\eta_c(2S) \rightarrow \eta_c(1S)\pi^+\pi^-)/\Gamma(\psi(2S) \rightarrow J/\psi\,\pi^+\pi^-)$ ~2.9
  M.B.Voloshin Mod. Phys. Lett A17:1533-1538,2022

- If the X (3872) is the 1^1D_2 state η_{c2} the branching fraction $B(X(3872) \rightarrow \eta_c \pi^+\pi^-)$ could be significantly larger than $B(X(3872) \rightarrow J/\psi\,\pi^+\pi^-)$.
  S. L. Olsen (Belle Collaboration), Int. J. Mod. Phys. A497 20, 240 (2005).

- The quantum numbers $J^{PC} = 2^{-+}$ of the η_{c2} are consistent with CDF results
  PRL 98, 132002

$\gamma\gamma \rightarrow \eta_c \pi^+\pi^-$ at BaBar



$\chi_{c2}(1P)$

$\eta_c(2S)$

X(3872)
X(3915)
$\chi_{c2}(2P)$

Signal extraction in two steps

1. $m(K_s^0K^\pm\pi^\mp)$ distribution parameters of the combinatoric background from a one-dimensional fit to $m(K_s^0K^\pm\pi^\mp)$
2. two-dimensional fit in $m(K_s^0K^\pm\pi^\mp)$ and $m(K_s^0K^\pm\pi^\mp\pi^+\pi^-)$

contribution from non-resonant

$$\gamma\gamma \rightarrow X \rightarrow K_s^0 K^\pm \pi^\mp \pi^+ \pi^-$$

Resonance	$\Gamma_{\gamma\gamma}\mathcal{B}$(eV)	
	Central value	UL
$\chi_{c2}(1P)$	$7.2^{+5.5}_{-4.4} \pm 2.9$	15.7
$\eta_c(2S)$	$65^{+47}_{-44} \pm 18$	133
$X(3872)$	$-4.5^{+7.7}_{-6.7} \pm 2.9$	11.1
$X(3915)$	$-13^{+12}_{-12} \pm 8$	16
$\chi_{c2}(2P)$	$-16^{+15}_{-14} \pm 6$	19

Using $B(\chi_{c2}(1P) \rightarrow K_s^0K^\pm\pi^\mp)$ and $B(\eta_c(2S) \rightarrow K_s^0K^\pm\pi^\mp)$ we obtain:

$B(\chi_{c2}(1P) \rightarrow \eta_c(1S)\pi\pi) < 2.2\%$ @90%CL
$B(\eta_c(2S) \rightarrow \eta_c(1S)\pi\pi) < 7.4\%$ @90%CL

first measurements

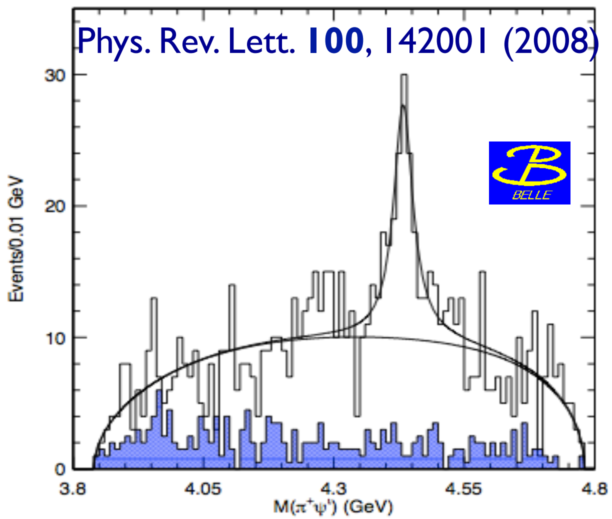
charged charmonia

$Z(4430)^+$, $Z_1(4050)^+$ and $Z_2(4250)^+$

Charged charmonia

- Belle observes broad, **charged** charmonium-like states in $(c\bar{c})K\pi$ Dalitz analyses
  - $Z(4430)^+$ in $B \to \psi(2S)\,\pi^+K$,
  - $Z_1(4050)^+$ and $Z_2(4250)^+$ in $B \to \chi_{c1}\,\pi^+K$

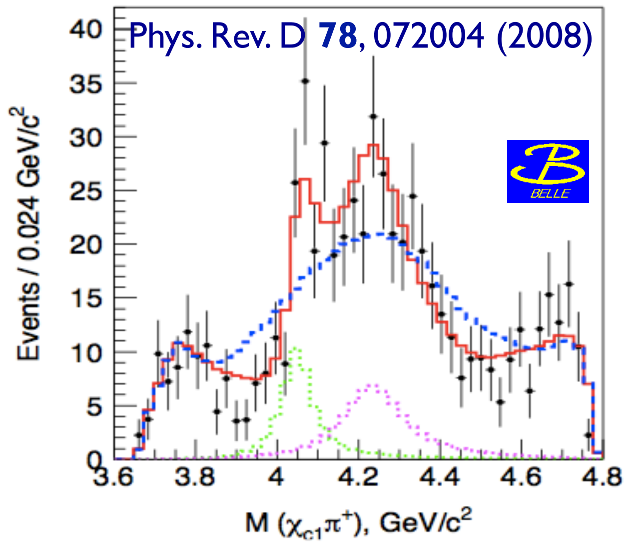
- Quark content at least $c\bar{c}ud$: no simple $q\bar{q}$ meson!



$Z_c(4430)^+ \to \psi'\pi^+$

Not confirmed by BaBar experiment that studied also the $J/\psi(2S)\pi^+K$ channel

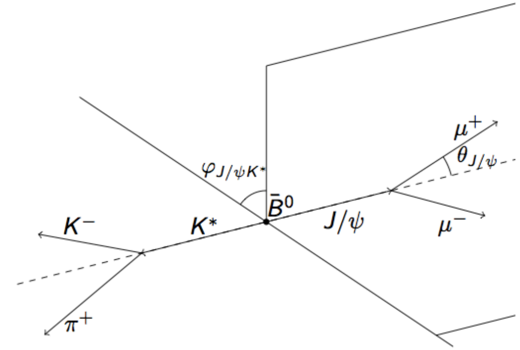
Phys.Rev. D79 (2009) 112001



$Z_c(4050)^+ \to \chi_{c1}\pi^+$ and $Z_c(4250)^+ \to \chi_{c1}\pi^+$

$\bar{B}^0 \to J/\psi(2S)\pi^+K^-$ amplitude analysis at Belle

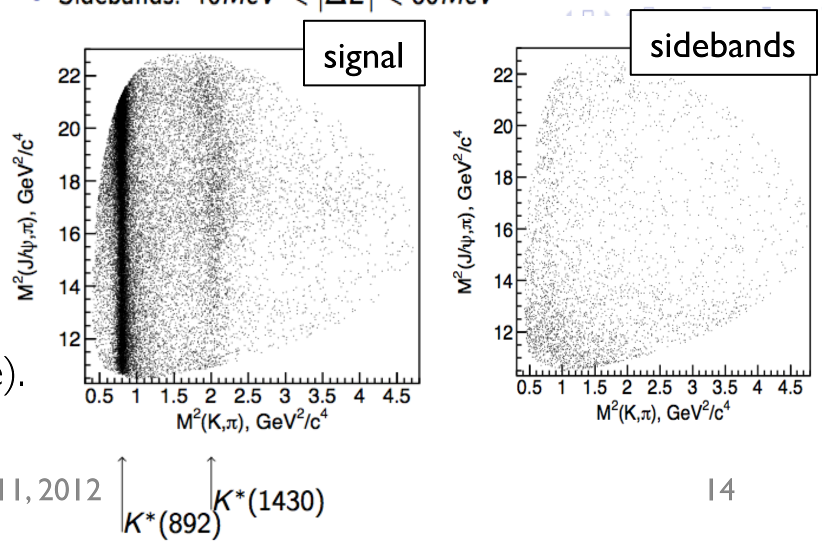
presented by K.Chilikin @ CHARM12



- The variables considered are Dalitz variables $M^2(K,\pi)$, $M^2(J/\psi,\pi)$ and angles $\theta_{J/\psi}$, $\phi_{J/\psi K*}$
- Signal model
  - All $K\pi$ resonances: $K_0^*(800)$, $K^*(892)$, $K^*(1410)$, $K_0^*(1430)$, $K_2^*(1430)$, $K^*(1680)$, $K_3^*(1780)$, $K_0^*(1950)$, $K_2^*(1980)$, $K_4^*(2045)$.
  - Masses and widths of all K* resonances are free parameters (within their PDG uncertainties).
  - 1 Z_c^+ (M, Γ are free). $J^P = 0^-, 1^+, 1^-, 2^+, 2^-$.
  - Constant non-resonant amplitude.
- Background model
  1. Peaking components:
     - $J/\psi + (K^*(892) \to K\pi)$
     - $J/\psi + (K_s^0 \to \pi\pi$ (identified as $K\pi$))
  2. Smooth component (dominant; any other source).

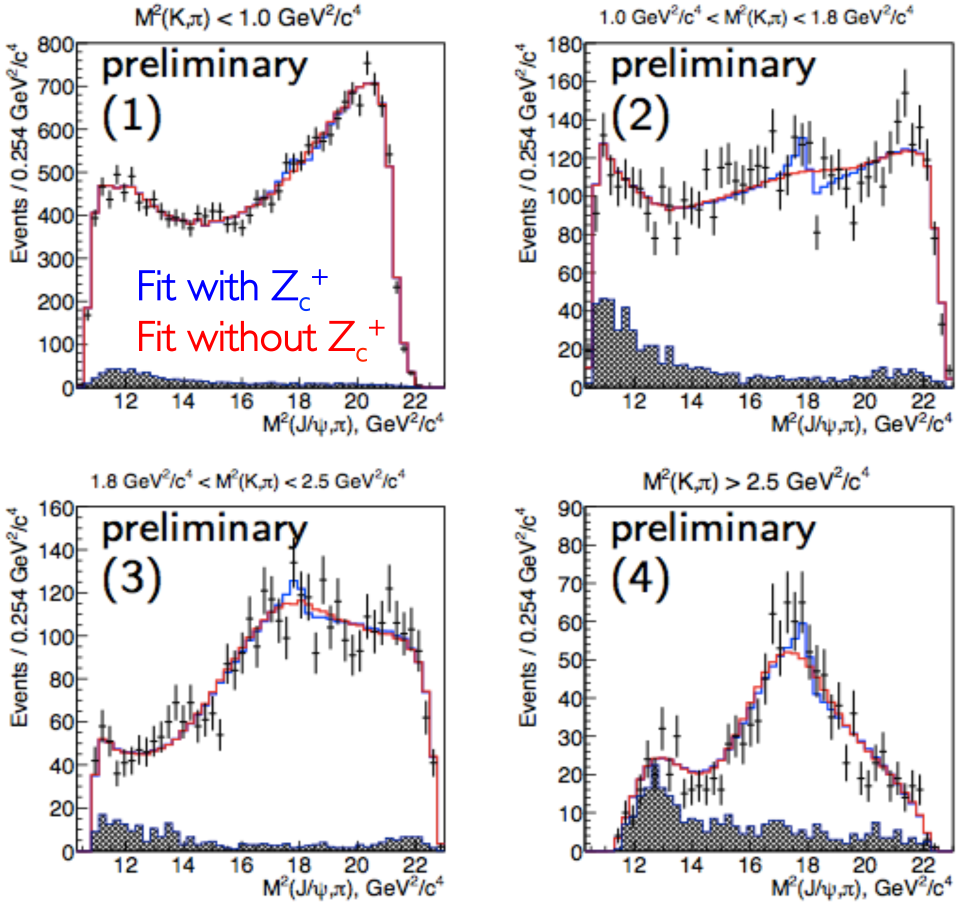
Here $\Delta E = \sum_i E_i - E_{\mathrm{beam}}$.

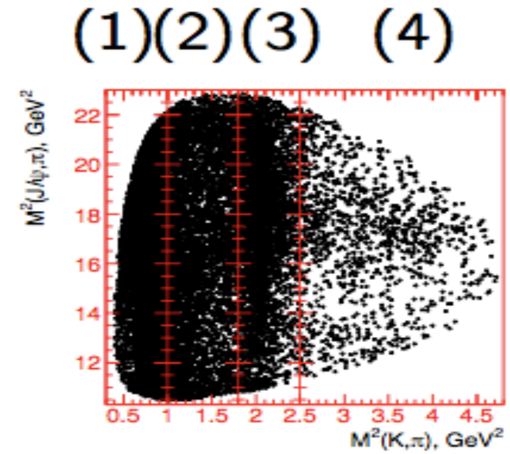
- Signal: $|\Delta E| < 20 MeV$ (31220 events, background fraction ~ 6%)
- Sidebands: $40 MeV < |\Delta E| < 80 MeV$



$\bar{B}^0 \to J/\psi\,(2S)\,\pi^+ K^-$ at Belle

presented by K.Chilikin @ CHARM12





No significant signal of Z_c^+ is found.

J^P	M, MeV	Γ, MeV	Local sign.	Sign.
	$Z_c^+ \to J/\psi\pi^+$			
0^-	4076 ± 17	240 ± 21	4.7σ	2.9σ
	4228 ± 8	51 ± 15	4.5σ	2.8σ
1^-	4108 ± 9	55 ± 12	4.5σ	2.8σ
1^+	4241 ± 6	40 ± 10	4.6σ	3.0σ
2^-	3942 ± 10	57 ± 24	2.9σ	0.7σ
2^+	4669 ± 5	26 ± 5	3.8σ	2.5σ
	$Z_c(4430)^+ \to J/\psi\pi^+$			
0^-	4437 ± 18	122 ± 44	1.6σ	0.8σ
1^-	4446 ± 21	171 ± 54	1.3σ	1.2σ
1^+	4450 ± 15	129 ± 22	4.1σ	3.1σ
2^-	4427 ± 10	47 ± 22	2.1σ	0.7σ
2^+	4443 ± 11	153 ± 46	$< 0.1\sigma$	$< 0.1\sigma$

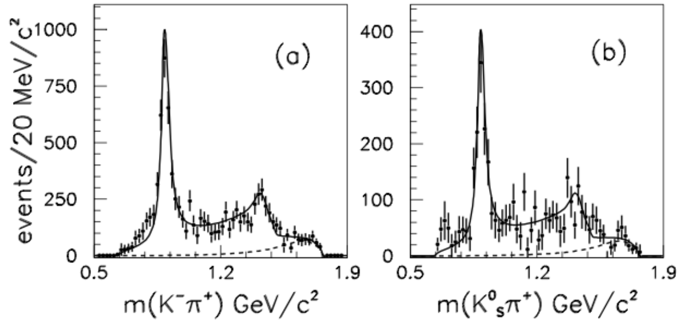
$$\mathcal{B}(\bar{B}^0 \to Z_c(4430)^+ K^-)\mathcal{B}(Z_c(4430)^+ \to J/\psi\pi^+) < 8 \times 10^{-6}\ (95\ \%\ \mathrm{CL})$$

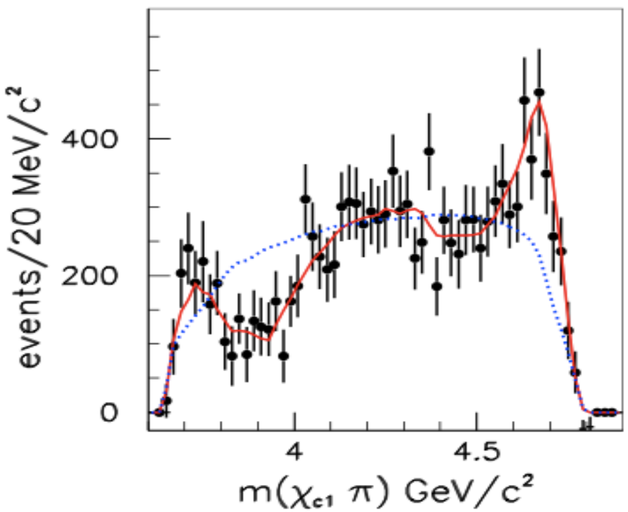
BaBar result: $< 4 \times 10^{-6}$ Phys.Rev. D79 (2009) 112001

Search for $Z_1(4050)^+, Z_2(4250)^+$ at BaBar

analysis procedure

- Study of $B \to \chi_{c1} K\pi$ decays to search for $Z_1(4050)^+$ and $Z_2(4250)^+$ found by Belle.
  - $\bar{B}^0 \to \pi^+ K^- \chi_{c1}$
  - $B^+ \to \pi^+ K_s^0 \chi_{c1}$
  - $\chi_{c1} \to J/\psi\, \omega$





χ^2 fits to the background subtracted and efficiency-corrected $k\pi$ mass spectra in terms of S, P and D wave amplitudes.

Compute the efficiency-corrected Legendre polynomial moments $< Y_L^0 >$ in each $k\pi$ mass interval by correcting for efficiency and then weighting each event by the $Y_L^0(\cos\theta)$ functions.

Using the information from the $K\pi$ system a description of the $\chi_{c1}\pi$ mass distribution is studied.

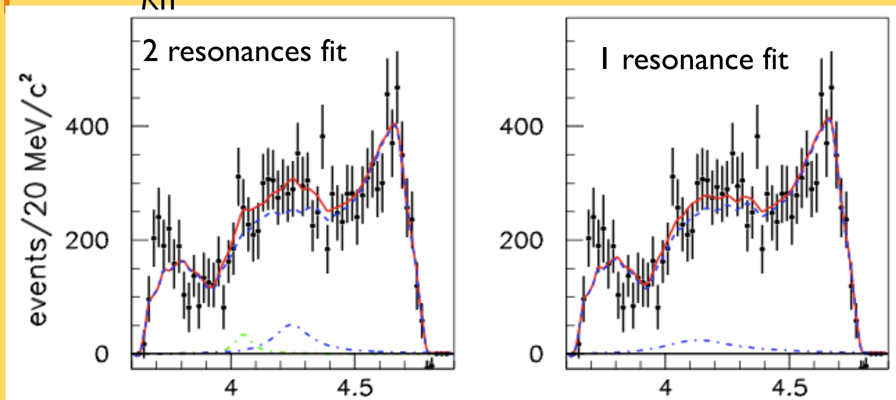
The excellent description of the data indicates that the angular information from the $K\pi$ channel is able to account for the structures observed in the $\chi_{c1}\pi$ projection.

BaBar results for $Z_1(4050)^+, Z_2(4250)^+$

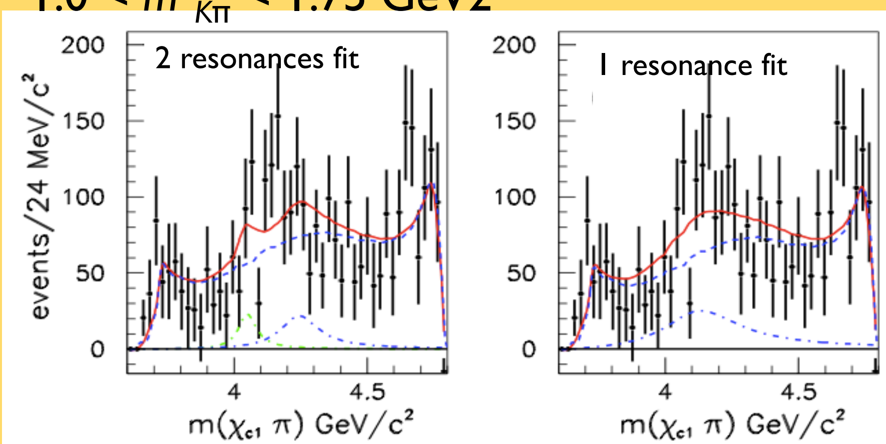
429fb^{-1}

Phys. Rev. D **85**, 052003 (2012)

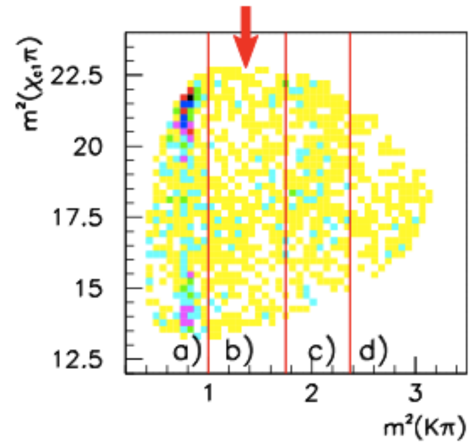
all $m^2_{K\pi}$



$1.0 < m^2_{K\pi} < 1.75$ GeV2



Belle: maximal resonant activity in window $1.0 < m^2_{K\pi} < 1.75$ GeV2



Set upper limits at 90%*C.L.*

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

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

For a single $Z(4150)^+$, upper limit

$$\mathcal{B}(\bar{B}^0 \to Z^+ K^-) \times \mathcal{B}(Z^+ \to \chi_{c1}\pi^+) < 4.7 \times 10^{-5}$$

Within (large) uncertainties, limits compatible with Belle's results Belle, Phys. Rev. D **78**, 072004 (2008)

new states with strange content

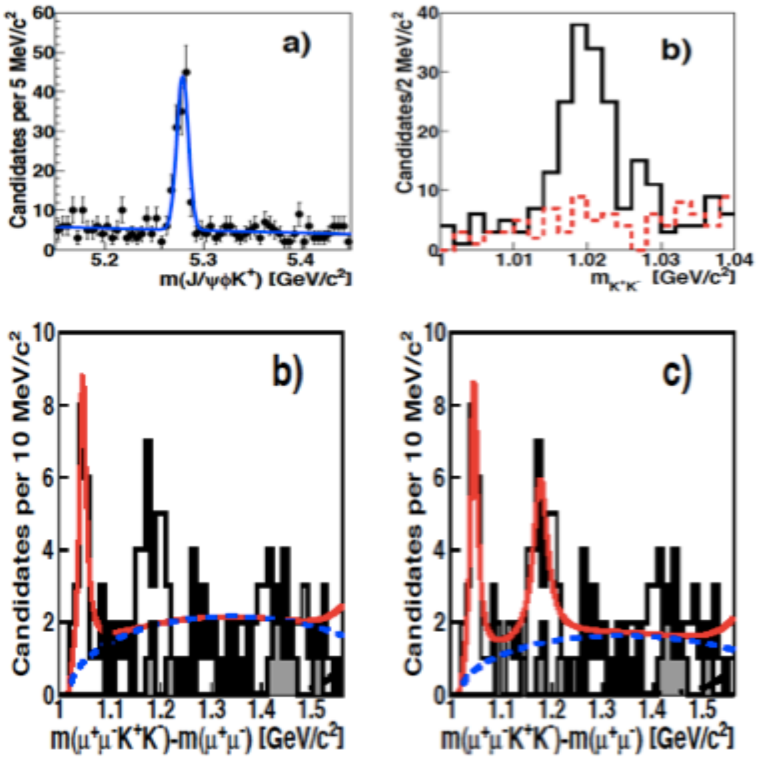
Y(4140), X(4274)

New states to J/ψ ϕ

PRL 102, 242002 (2009)

- CDF studied $B^+ \rightarrow J/\psi\, \phi\, K^+$ decays and found an excess of events in the Jψ ϕ invariant mass at threshold

- Updated in arXiv:1101.6058



Allowed $J^{PC} = 0^{++}, 1^{+-}, 2^{++}$

$$Y(4140): \quad 19 \pm 6 \pm 3\,\text{evts} \quad (5\,\sigma)$$

$$M = 4143^{+2.9}_{-3.0} \pm 0.6\,\text{MeV}/c^2$$

$$\Gamma = 11.7^{+8.3}_{-5.0} \pm 3.7\,\text{MeV}$$

$$\frac{\mathcal{B}(B^+ \to YK^+) \times \mathcal{B}(Y \to J\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} = 0.149 \pm 0.039 \pm 0.024$$

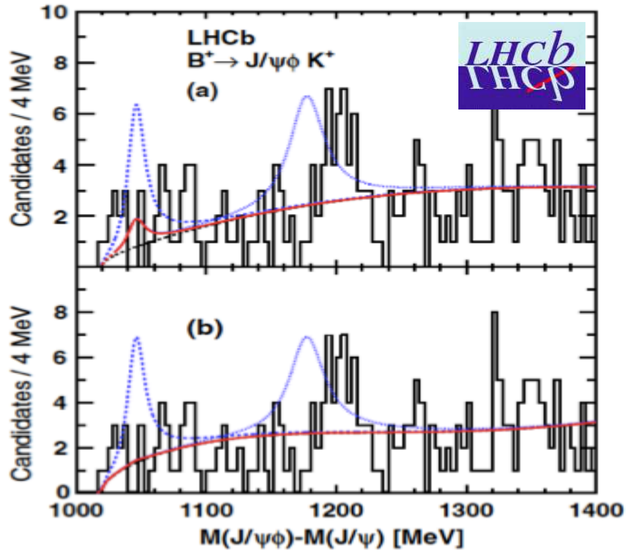
$$X(4274): \quad 22 \pm 8\,\text{evts} \quad (3.1\,\sigma)$$

$$M = 4274.4^{+8.4}_{-6.7} \pm 1.9\,\text{MeV}/c^2$$

$$\Gamma = 32.3^{+21.9}_{-15.3} \pm 7.6\,\text{MeV}$$

$J/\psi\ \Phi$ study at LHCb and Belle

- LHCb searched for $J/\psi\ \phi$ resonances in $B^+ \rightarrow J/\psi\ \phi K^+$ PRD-RC 85, 091103 (2012)



Y(4140) : Expect: $35 \pm 9 \pm 6$ evts

< 16evts (a)

< 13evts (b)

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

X(4274) : Expect: 53 ± 19 evts

< 24evts (a)

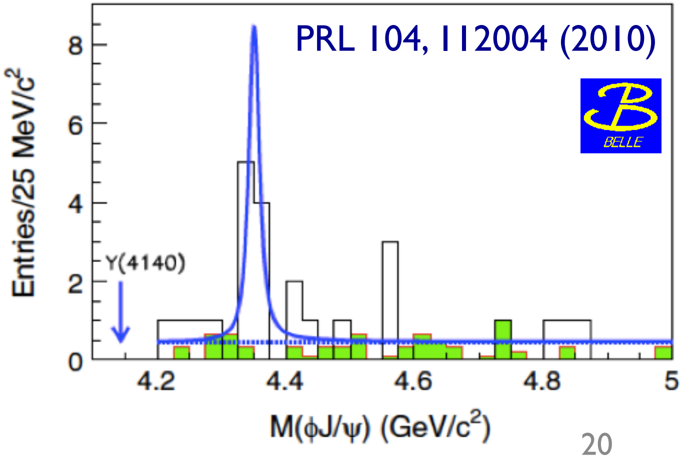
< 20evts (b)

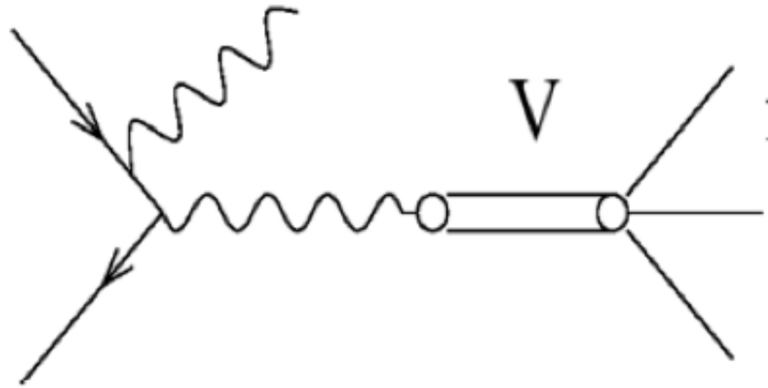
$$\frac{\mathcal{B}(B^+ \to YK^+) \times \mathcal{B}(X \to J\psi\phi)}{\mathcal{B}(B^+ \to J/\psi\phi K^+)} < 0.08$$

- Belle searched for $\gamma\ \gamma \rightarrow$ **Y(4140)** $\rightarrow \phi\ J/\psi$
- No evidence of the **Y(4140)**
- But find **3.1**σ evidence for a new structure

$$M = 4350.6^{+4.6}_{-5.1} \pm 0.7\ \text{MeV}/c^2$$

$$\Gamma = 13^{+18}_{-9} \pm 4\ \text{MeV}$$





$\psi\ \pi^+\pi^-$ spectrum after initial state radiation

$Y(4260) \rightarrow J/\psi\ \pi^+\pi^-$

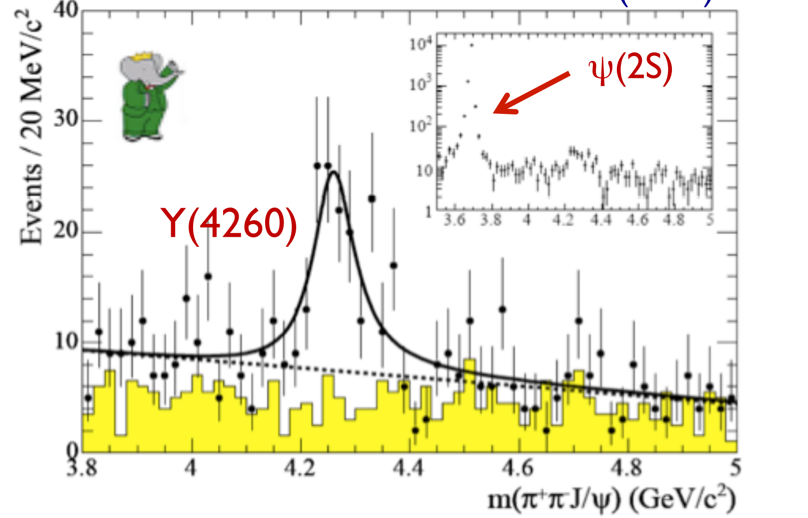
$Y(4330), Y(4660) \rightarrow \psi(2S)\ \pi^+\pi^-$

$e^+e^- \rightarrow \gamma_{ISR} J/\psi\ \pi^+\pi^-$

BABAR searched for states decaying to $J/\psi\ \pi^+\pi^-$ in ISR process ($J^{PC} = 1^{--}$).

- BaBar did not find the X(3872) nor one of its predicted partners but found an unexpected broad state around 4260 MeV.

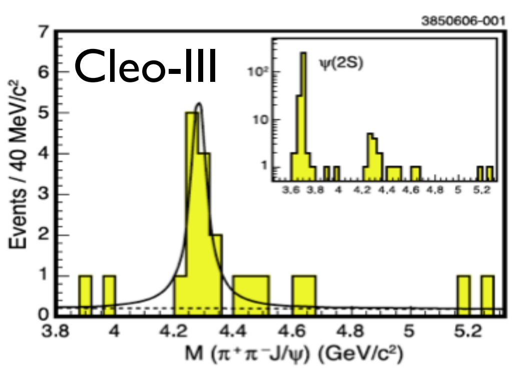
PRL 95(2005)142001



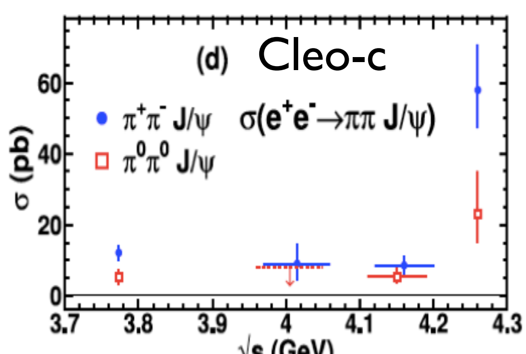
- the Y(4260) has been searched and not found in
  - many exclusive $D_{(s)}^{(*)}\bar{D}_{(s)}^{(*)}$ modes
  - many exclusive light hadron modes
  - $p\bar{p}$ final state

All 1^{--} slots in charmonium spectrum are filled: the nature of Y(4260) is still not clear

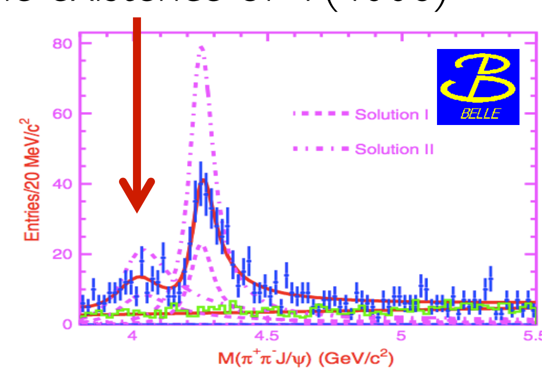
BELLE confirmed the Y(4260) and suggested the existence of Y(4008)



PRL 96(2006)162003



PRD 74(2006)091104(R)



PRL 99(2007)182004

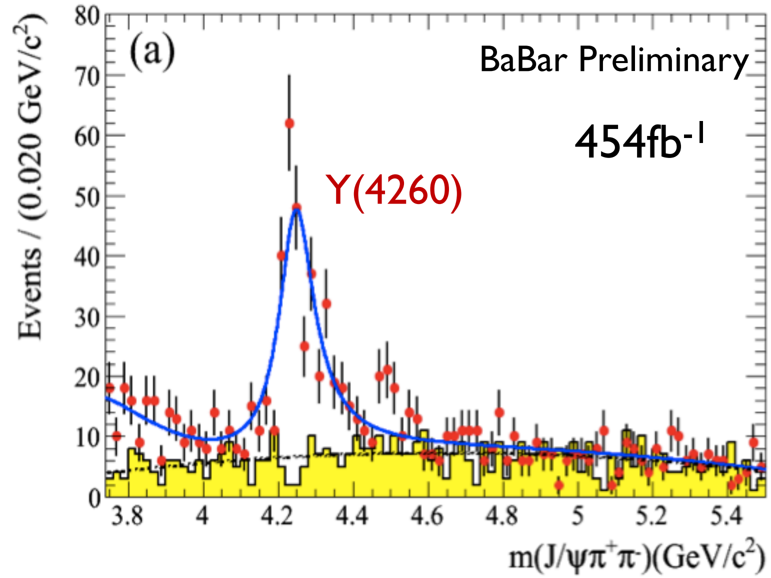
Y(4260): BaBar preliminary resulta

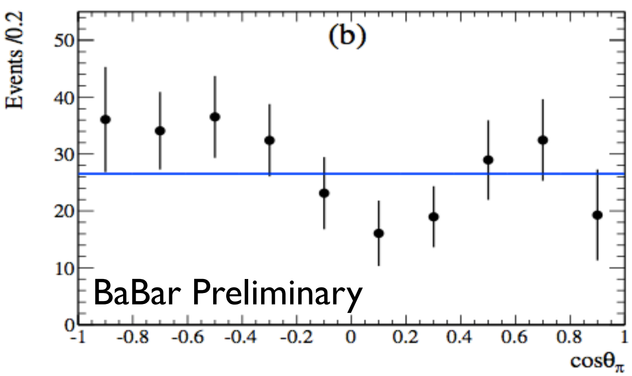
arXiv:1204.2158
submitted to PRD

$$\text{Mass } (Y(4260)) = 4244 \pm 5 \pm 4 \text{ MeV}/c^2$$
$$\Gamma(Y(4260)) = 114^{+16}_{-15} \pm 7 \text{ MeV}$$
$$\Gamma_{e^+e^-} X B(J/\psi\pi^+\pi^-) = 9.2 \pm 0.8 \pm 0.7 \text{ eV}$$

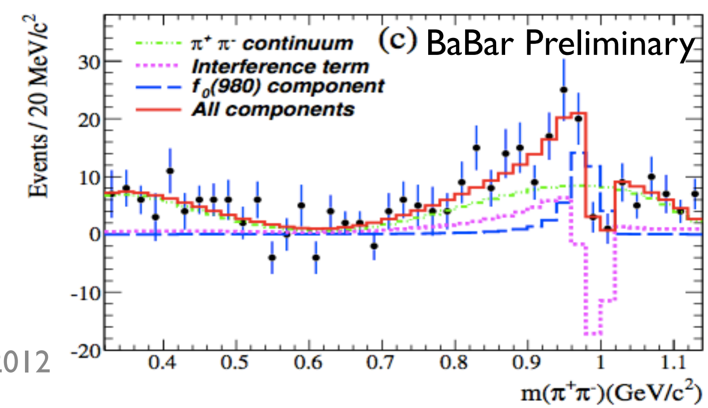
in agreement with Belle's results

- The π^+ angle with respect to the J/ψ direction in the $\pi^+\pi^-$ rest frame is consistent with S-wave





- fit the $\pi^+\pi^-$ invariant mass distribution as a coherent sum of NR + $f_0(980)$.
- mass dependence of $f_0(980)$ amplitude and phase from $D_s^+ \rightarrow \pi^+\pi^-\pi^+$ DP analysis. PRD 79, 032003 (2009)

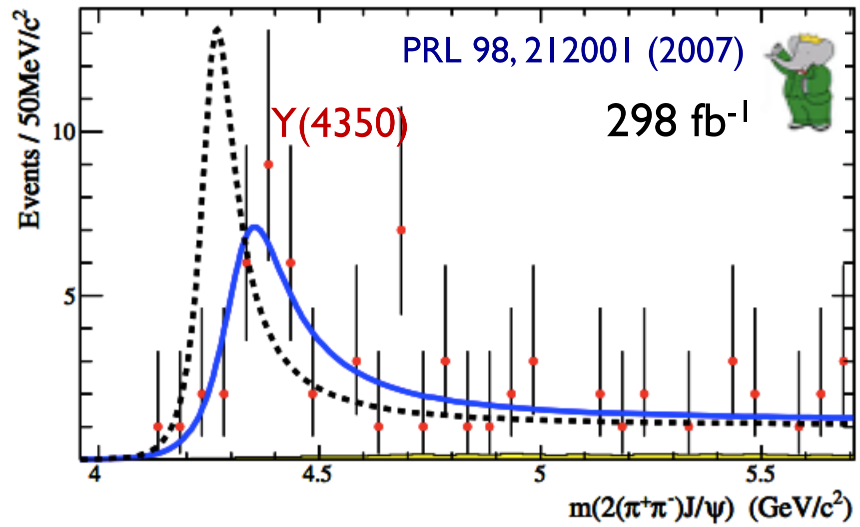


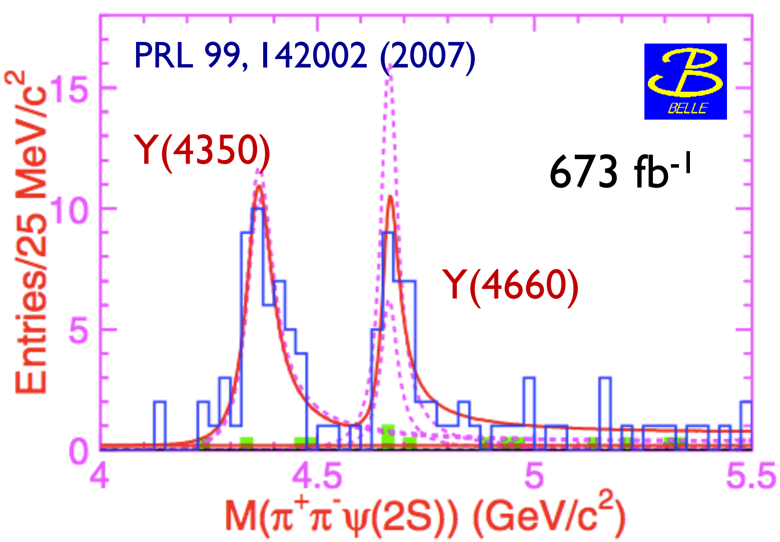
BaBar Preliminary

$$\frac{B(Y_{4260} \rightarrow J/\psi f_0(980), f_0(980) \rightarrow \pi^+\pi^-)}{B(Y_{4260} \rightarrow J/\psi\pi^+\pi^-)} = (17 \pm 13)\%$$

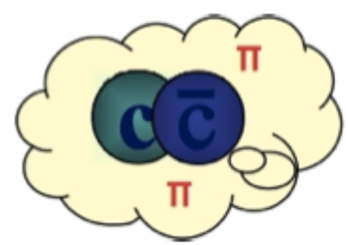
Y (4350) and Y (4660) → $\psi(2S)\,\pi^+\pi^-$

- Y(4350) observed by BaBar in ISR $\psi(2S)\,\pi^+\pi^-$
- Confirmed by Belle, which reported a significant excess also at 4660 MeV
- No evidence for Y(4260)





- Why are there states decaying into 2^3S_1 and not to 1^3S_1?



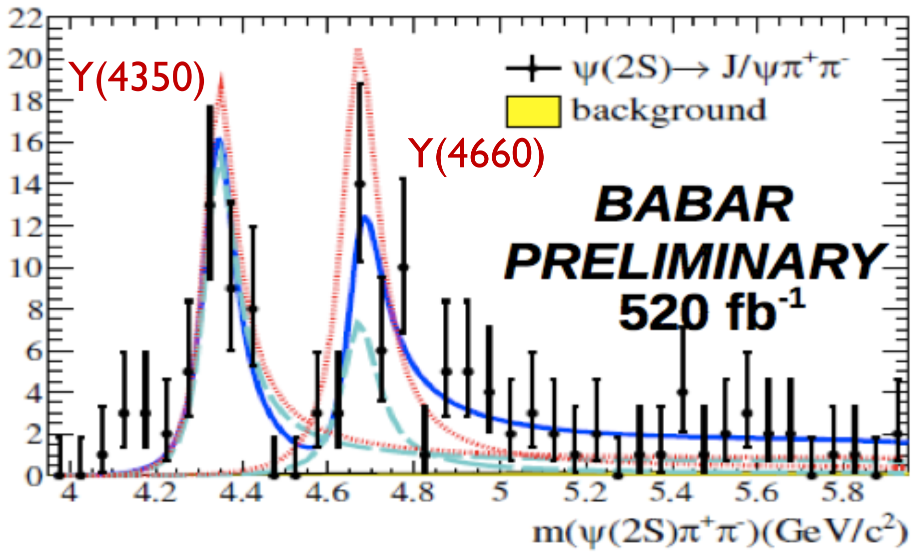
hadro-charmonium?

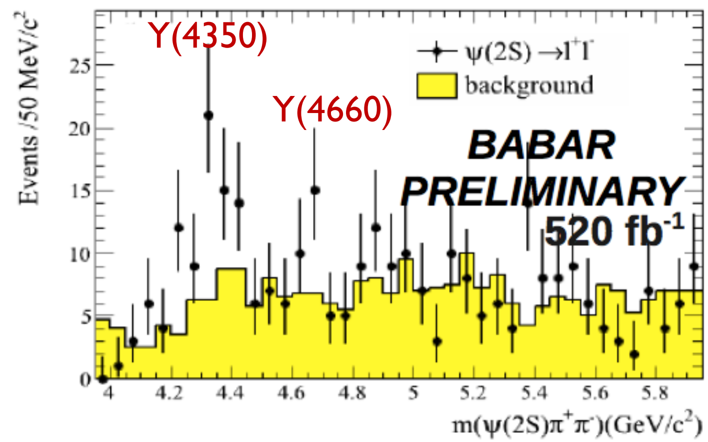
M.B. Voloshin arXiv:0711.4556

Dubynsky & Voloshin PLB 671 (2009) 82

ψ(2S) $\pi^+\pi^-$: new BaBar result

- BABAR update using the full dataset, including Υ (2S) and Υ (3S)
- Use both ψ(2S) $\rightarrow$ J/$\psi\,\pi^+\pi^-$ and ψ(2S) $\rightarrow l^+l^-$

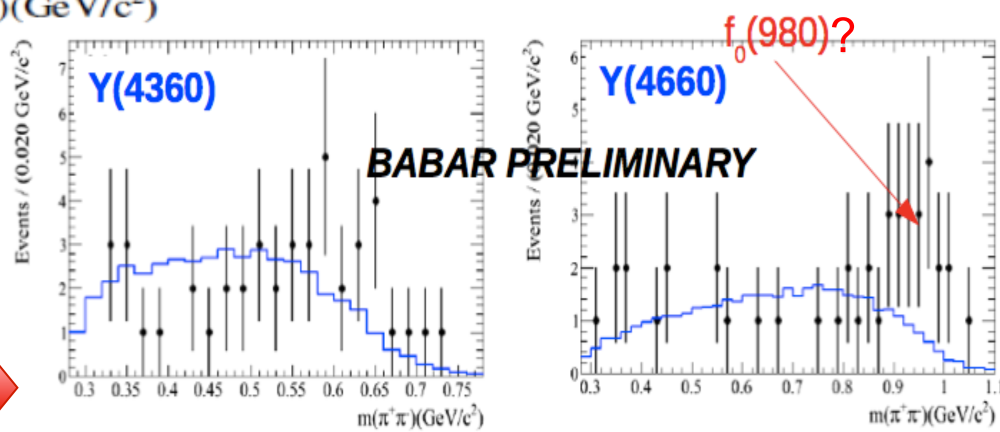




Mass(Y(4350)) = 4340±16±9 *MeV/c²*
Γ(Y(4350)) = 94±32±13 *MeV*

Mass(Y(4660)) = 4669±21±3 *MeV/c²*
Γ(Y(4660)) = 104±48±10 *MeV*

statistics too low to draw conclusions on $\pi^+\pi^-$ invariant mass distribution



~~Outline~~ Summary

- charmonium like states in $\gamma\gamma$ interaction
  - $\gamma\gamma \rightarrow J/\psi\ \omega$
  - $\gamma\gamma \rightarrow \eta_c\ \pi^+\pi^-$

new results have been presented for the X(3915) and X(3872): overall agreement among different experiments, nevertheless the nature of the resonances is still matter of discussion

- charged charmonia (Z^+, Z_1^+, Z_2^+)

the interpretation would be clear, but complete disagreement between BaBar and Belle. LHCb studies in progress: should have more statistics than BaBar+Belle

- states with strange content: $J/\psi\ \phi$.

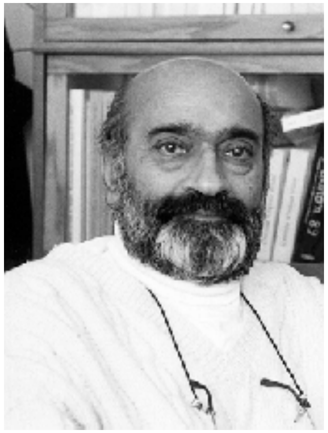
disagreement between CDF, LHCb and Belle experiments. Waiting for BaBar result.

- $\psi(1S, 2S)\ \pi^+\pi^-$ spectrum after initial state radiation

The overpopulation of $J^{PC}=1^{--}$ states after ISR and their many null searches make this family of new states hard to be interpreted.

and conclusion

- Quarkonium spectroscopy is a very interesting and vital field; many new exotic states have been discovered in less than one decade.
- New exciting results are still coming from BaBar and Belle, more to come from LHC.
- Still many missing pieces need to be found to have the full picture.
- Even more exciting new results can be expected in the not-too-distant future by the next-generation B-factories

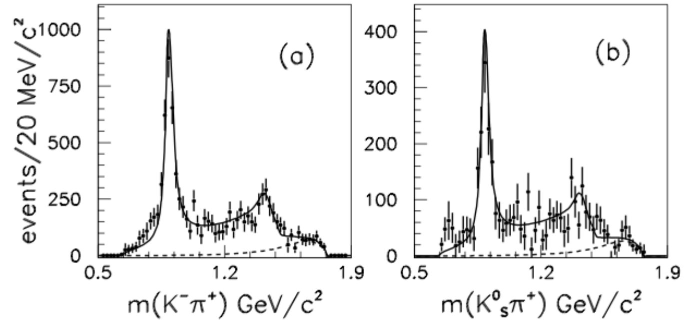


in memory of
Popat Patel
colleague and friend

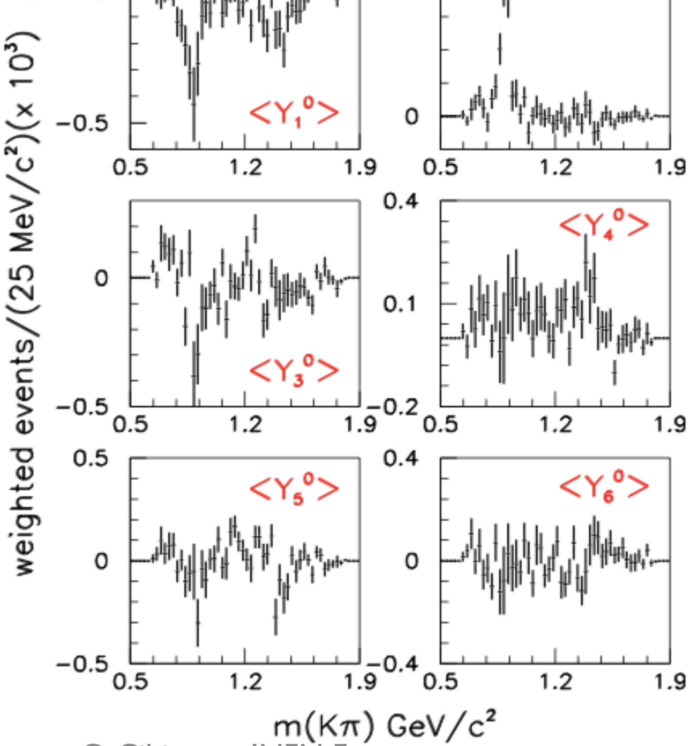
Search for $Z_1(4050)^+, Z_2(4250)^+$ at BaBar

analysis procedure

- Study of $B \rightarrow \chi_{c1} K\pi$ decays to search for $Z_1(4050)^+$ and $Z_2(4250)^+$ found by Belle.
  - $\bar{B}^0 \rightarrow \pi^+ K^- \chi_{c1}$
  - $B^+ \rightarrow \pi^+ K_s^0 \chi_{c1}$
  - $\chi_{c1} \rightarrow J/\psi\, \omega$



Binned χ^2 fits to the background subtracted and efficiency-corrected $k\pi$ mass spectra in terms of S, P and D wave amplitudes.



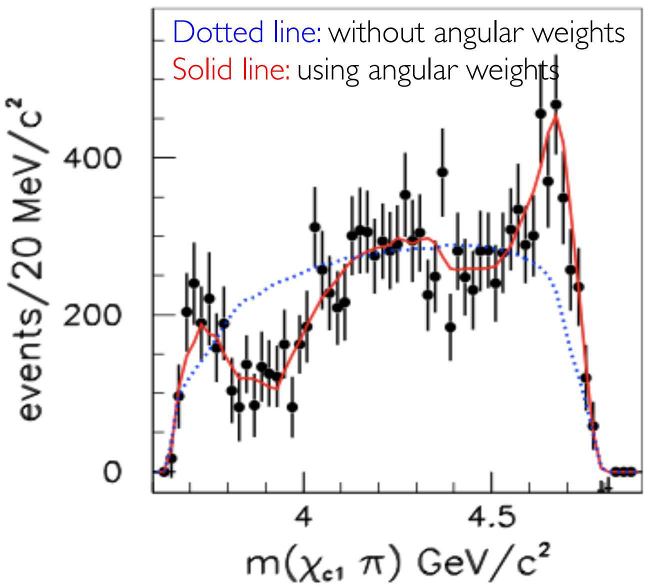
Compute the efficiency-corrected Legendre polynomial moments $< Y_L^0 >$ in each $k\pi$ mass interval by correcting for efficiency and then weighting each event by the Y_L^0 $(\cos\theta)$ functions.

- S-P interference in the $< Y_1^0 >$ moment.
- Hint at 1.7 GeV in $< Y_1^0 >$ indicate the presence of a P-wave
- Presence of the spin-1 K*(890) in the $< Y_2^0 >$ moment
- Presence of the spin-2 K_2*(1430) in the $< Y_4^0 >$ moment
- $< Y_6^0 >$ is consistent with zero → The presence of scalar Z resonances should show up especially in high $< Y_L^0 >$ moments

Search for $Z_1(4050)^+, Z_2(4250)^+$ at BaBar

data driven MC simulation

- Using the information from the $K\pi$ system a description of the $\chi_{c1}\pi$ mass distribution is studied. A MC simulation for $B \rightarrow \chi_{c1}K\pi$ has been performed. The best χ^2/NDF obtained is for $L_{max} = 5$.



The result of the simulation with $L_{max} = 5$ is superimposed on the data.

The excellent description of the data indicates that the angular information from the $K\pi$ channel with $L_{max} = 5$ is able to account for the structures observed in the $\chi_{c1}\pi$ projection.

This indicates the absence of significant structure in the exotic $\chi_{c1}\pi^+$ channel.

A 25% contribution of $Z_2^+(4250)$ in the $\bar{B}^0 \rightarrow \pi^+K^-\chi_{c1}$ is added on a MC simulation. The Legendre polynomial moments is then computed.

The resulting MC simulation does not describe the MC data well.