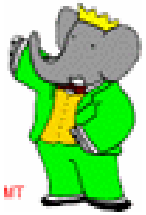
Recent Results on Meson Spectroscopy from Belle and BaBar



S.Uehara (KEK)

MESON2010, Jagiellonian University, Krakow
June 10-15, 2010

Outline

- New charmonium(-like) states
  X(3872), Z(4430)
  X(3940), Y(3940), Z(3930)
  Y(4140) , X(4350)

- Possible $b\bar{b}$ exotic state Y_b

- Properties of η_c, η_b, Y(1D)

List of new mesons

recently found at B-factory Experiments etc.

(including some found by CLEOc and CDF)

Charmonium(-like) particles

$\eta_c(2S)$, $Z(3930)=\chi_{c2}(2P)$ // ordinary charmonium states

$X(3872)$, $Y(3940)$, $Z(4430)$, $Z(4058)$, $Z(4258)$, $Y(4260)$, $Y(4320)$, $Y(4008)$,

$Y(4664)$, $Y(4140)$, $X(3915)$, $X(4350)$ ... // decay into a charmonium

$X(3940)$, $X(4160)$, $X(4630)$

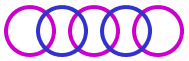
$D_{(S)}$-mesons

$D^*_0(2308)$, $D'_1(2427)$, $D_{sJ}(2700)$, $D^*_{s0}(2317)$, $D_{s1}(2460)$, $D_s(2690)$, $D_s(2860)$, …

Bottomonium(-like)

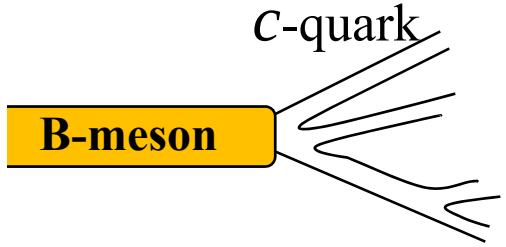
η_b, $Y_J(1D)$, Y_b

Light-quark mesons, baryons are not included in this table.



Hidden $c\bar{c}$ or $b\bar{b}$: Production at B-factory Experiments

Hadronic decays of B meson

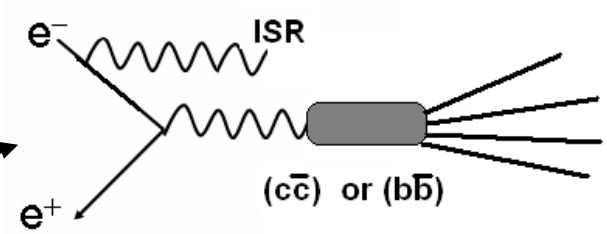


e^+e^- annihilation processes

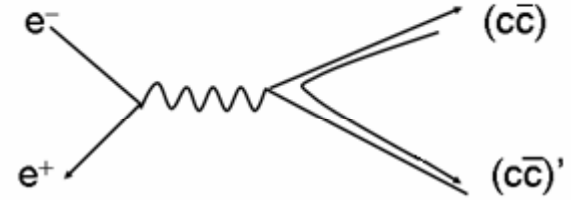
ISR processes

double charmonium production

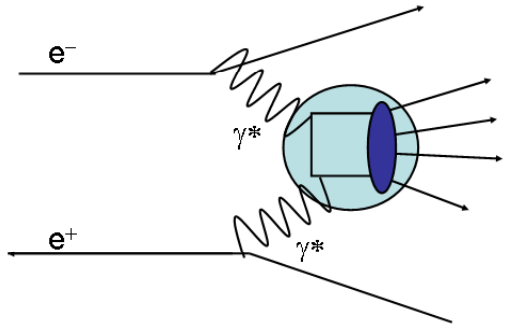
Y(nS) decays



C-odd



Two-photon collisions



C-even

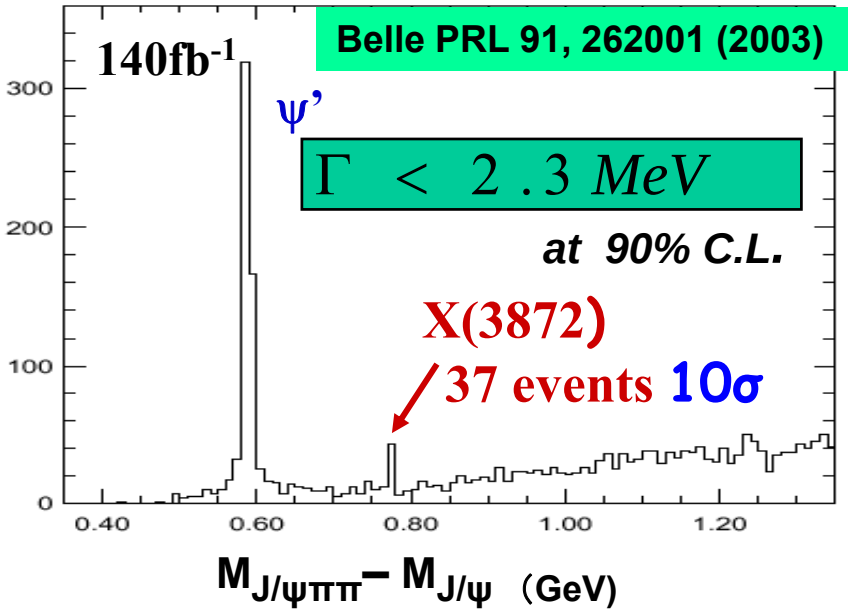
X(3872)

X(3872) and its properties

First observation @ BELLE

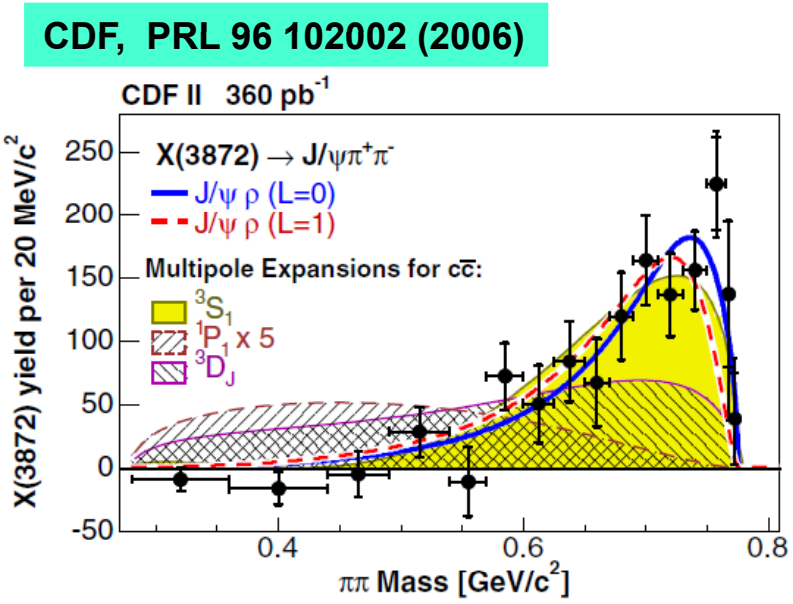
$B^- \rightarrow X(3872)K^-$

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



Belle, hep-ex/0505037

$X(3872) \rightarrow \gamma J/\psi$ seen **C-even**



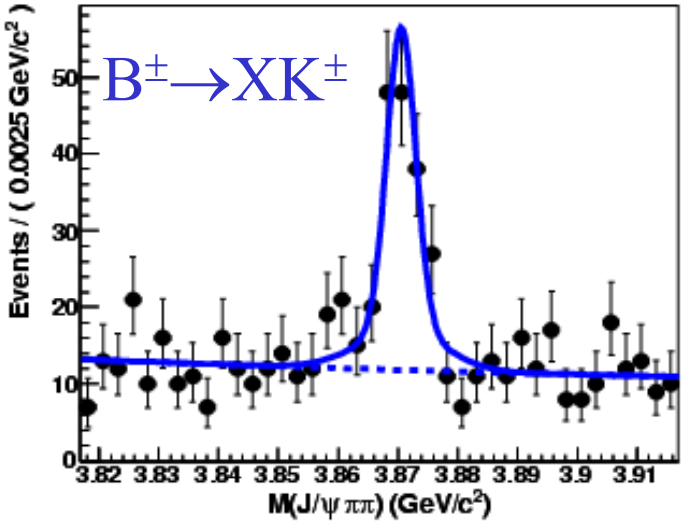
ππ mass distribution – ρ like

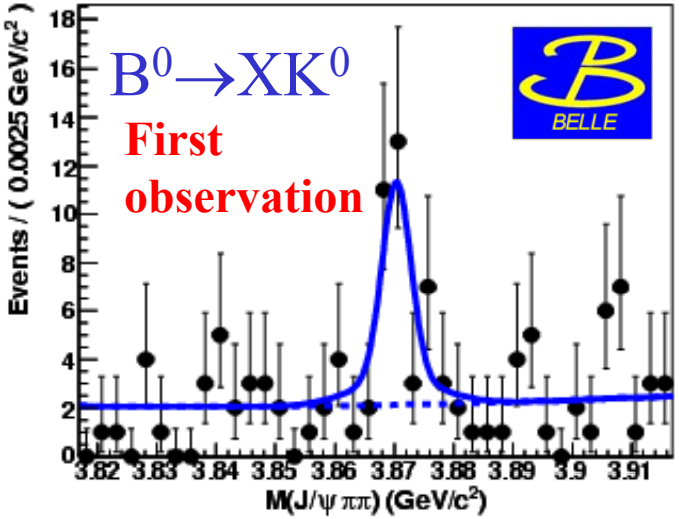
$J^P = 1^+$ and 2^- are favored

X(3872) production modes:
Decay of B^0: BF ratios and no-mass splitting

Doublet X? (from a diquark and anti-diquark model)

$B^{\pm} \to X(3872) K^{\pm}$ and $B^0 \to X(3872) K^0_S$





	M(X from $B^{\pm}$) – M(X from B^0)	BF($B^0 \to XK^0$) /BF($B^{\pm} \to XK^{\pm}$)
BaBar , 413 fb^{-1}	$+2.7 \pm 1.6 \pm 0.4$ MeV/c^2	$0.41 \pm 0.24 \pm 0.05$ PRD 77,111101(R) (2008)
Belle, 605 fb^{-1}	$+0.18 \pm 0.89 \pm 0.26$ MeV/c^2	$0.82 \pm 0.22 \pm 0.05$ arXiv:0809.1224

Belle: Mx $= 3871.46 \pm 0.37 \pm 0.07$ MeV/c^2

CDF: $M_x = 3871.61 \pm 0.16 \pm 0.19$ MeV/c^2

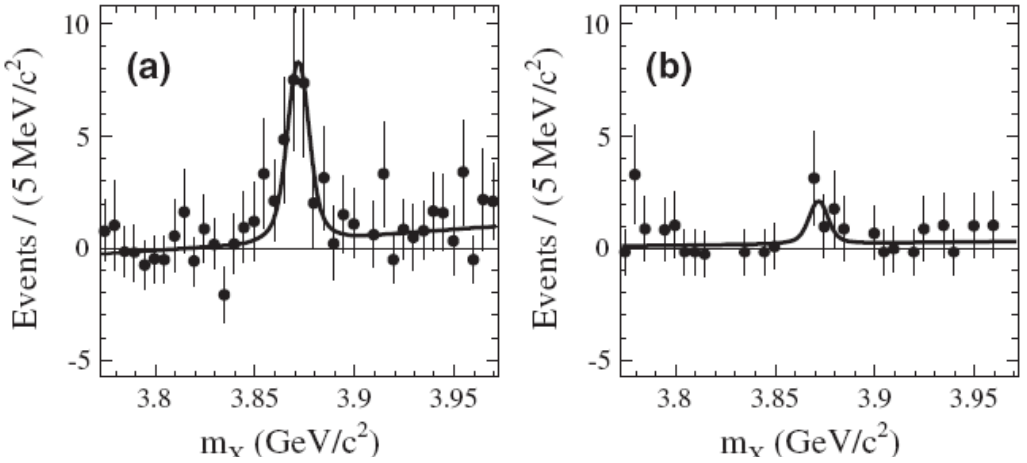
PRL 103,152001 (2009)

$M(D^0) + M(D^{*0}) = 3871.80 \pm 0.37$MeV/c^2

X(3872) decay modes: $\psi^{(\prime)}\gamma$

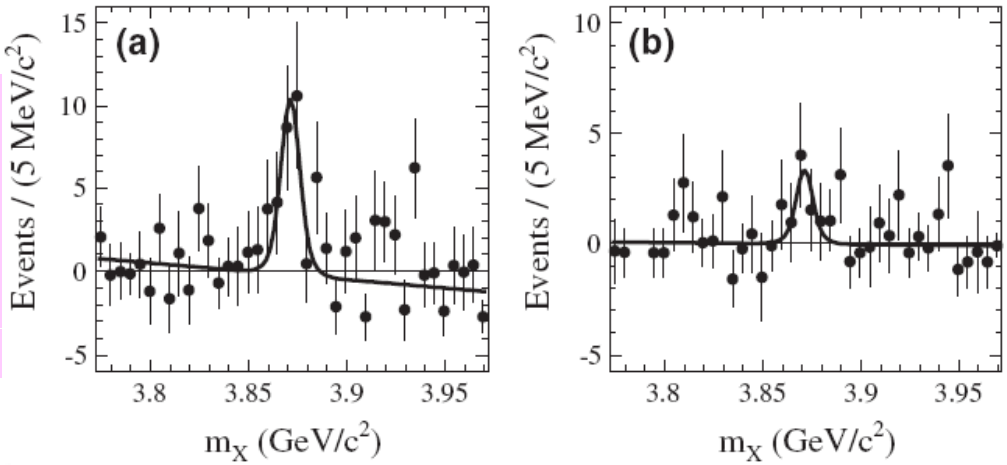
PRL 102, 132001 (2009)

$B^{\pm}\to XK^{\pm}$
$X\to J/\psi\,\gamma$



424 fb^{-1}
$B^0\to XK^0_S$
$X\to J/\psi\,\gamma$

$B^{\pm}\to XK^{\pm}$
$X\to\psi(2S)\,\gamma$
Evidence of new decay mode



$B^0\to XK^0_S$
$X\to\psi(2S)\,\gamma$

$$\mathcal{B}(B^{\pm}\to X(3872)K^{\pm})\times\mathcal{B}(X(3872)\to\psi(2S)\gamma)=[9.5\pm2.7(\text{stat})\pm0.6(\text{syst})]\times10^{-6}$$

BF ratio, $B(\psi(2S)\gamma)/B(J/\psi\gamma) = 3.4\pm1.4$

Inconsistent with a pure $D^0\overline{D}^{*0}$ molecule state

$\psi^{(\prime)}\gamma$ modes from Belle

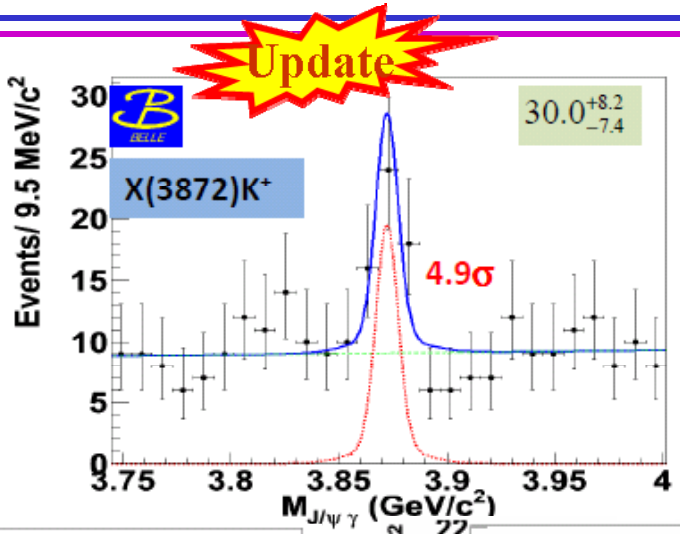
Belle , QWG 7(2010)

772M $B\bar{B}$

Preliminary

$B^{\pm} \to XK^{\pm}$

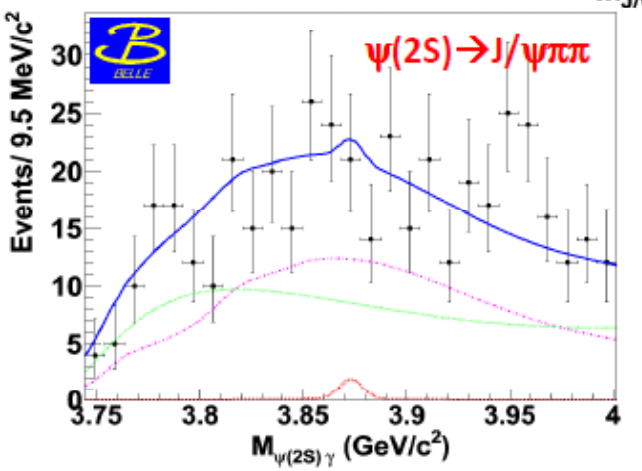
$X \to J/\psi\ \gamma$

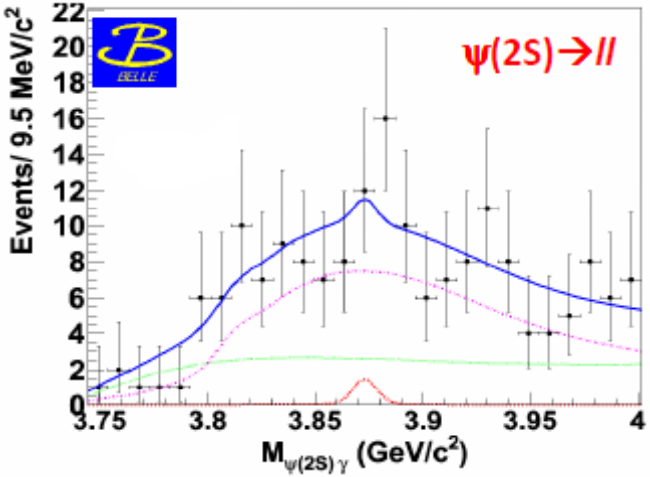


$B^{\pm} \to XK^{\pm}$

$X \to \psi(2S)\ \gamma$

NOT SEEN





$$\mathcal{B}(B^{\pm} \to X(3872)K^{\pm}) \times \mathcal{B}(X(3872) \to \psi(2S)\gamma) < 3.4 \times 10^{-6} \quad (90\%\text{CL})$$

$B(\psi(2S)\gamma)/B(J/\psi\gamma) < 2.1$ (90%CL)

Not in agreement with BaBar's evidence

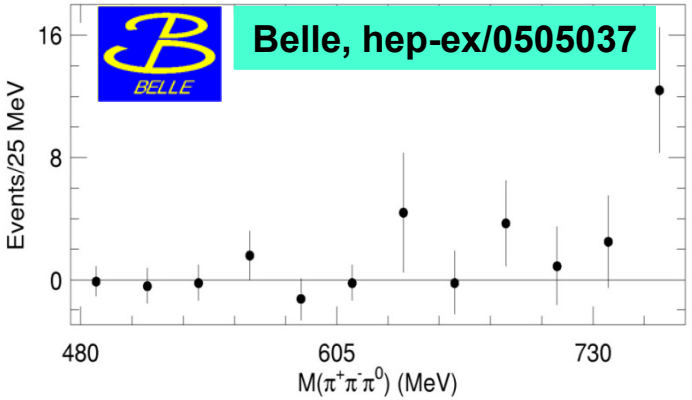
BaBar: BF × BF = $(9.5 \pm 2.7 \pm 0.6) \times 10^{-6}$

ω J/ψ mode

X(3872) →ωJ/ψ found at Belle

Just below the mass threshold

Covered by Γ(ω)= 8.5MeV



BaBar confirmed with a looser mass cut for ω

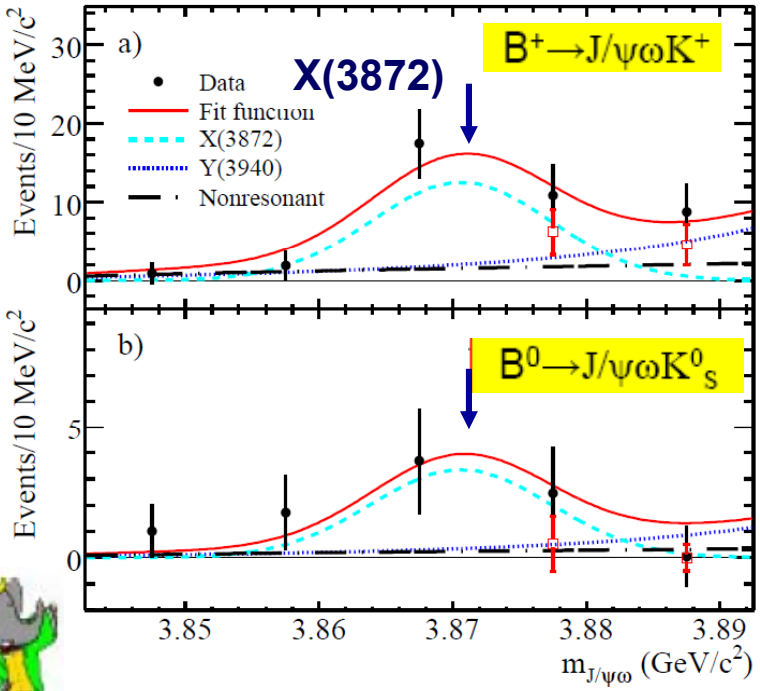
$0.7400 < m_{3\pi} < 0.7965$ (B^+)

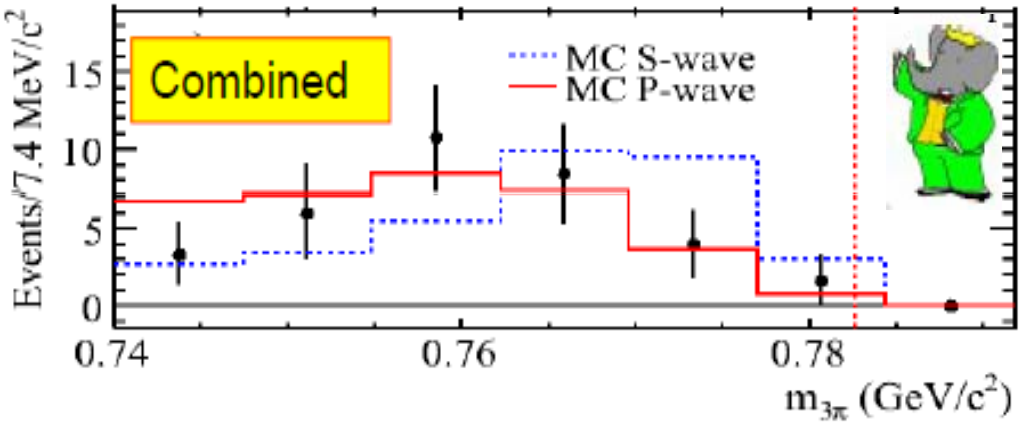
$0.7400 < m_{3\pi} < 0.8055$ (B^0)

New Analysis

BaBar, arXiv:1005.5190

426 fb^{-1}





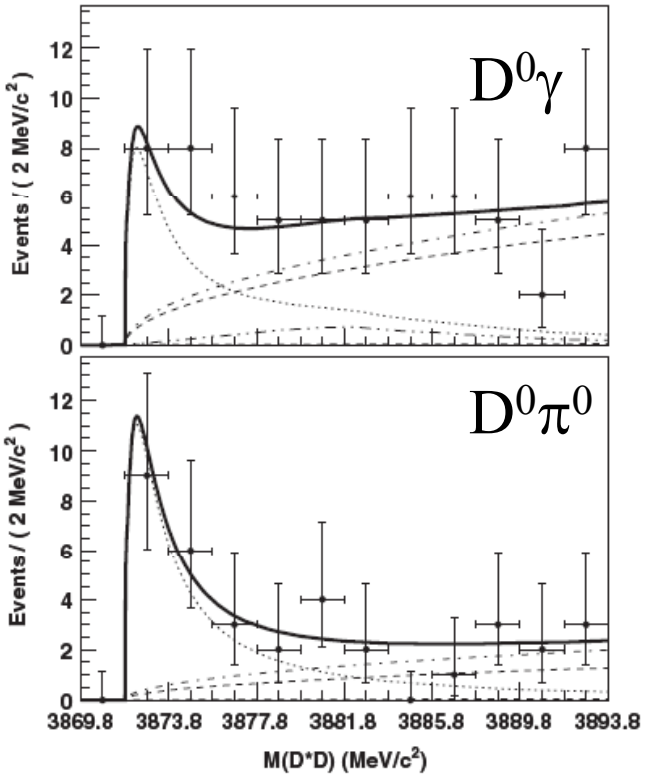
M(3π) distribution favors P-wave

$J^P(X) = 2^-$ rather than 1^+ ?

$D^0\bar{D}^{*0}$ mode

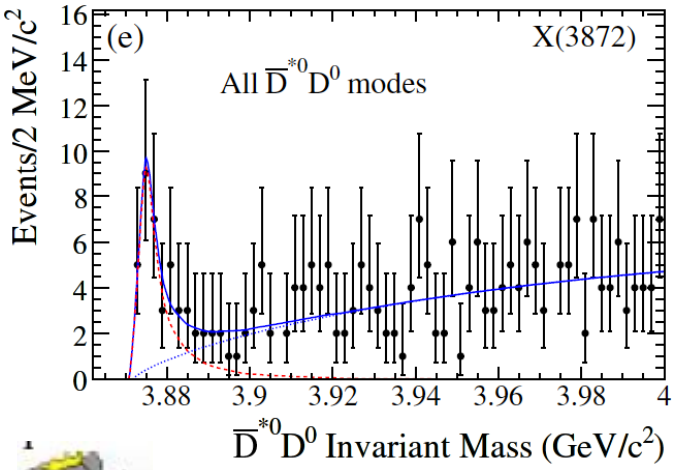
Use $D^{*0} \to D^0\pi^0$ and $D^0\gamma$ assuming known BF ratio

Belle, PRD 81, 031103(R) (2010)



605 fb^{-1}

BaBar, PRD 77, 011102 (2008)



$3875.1^{+0.7}_{-0.5} \pm 0.5$ MeV

$M = 3872.9^{+0.6\,+0.4}_{-0.4\,-0.5}$ MeV/c^2, $\Gamma = 3.9^{+2.8\,+0.2}_{-1.4\,-1.1}$ MeV,

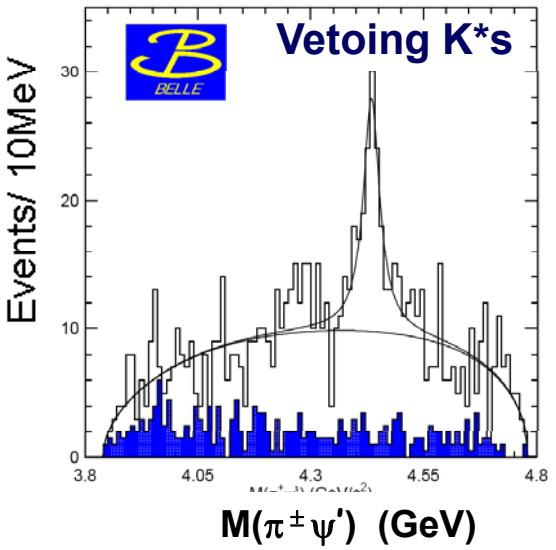
$BR(B^0 \to XK) \times BR(X \to \bar{D}^{*0}D^0) = (0.80 \pm 0.20 \pm 0.10) \times 10^{-4}$

No significant mass difference from the X(3872) in $J/\psi\,\pi^+\pi^-$ mode

Z(4430)

$Z(4430)^+$: Charged charmonium-like state

PRL 100, 142001 (2008)

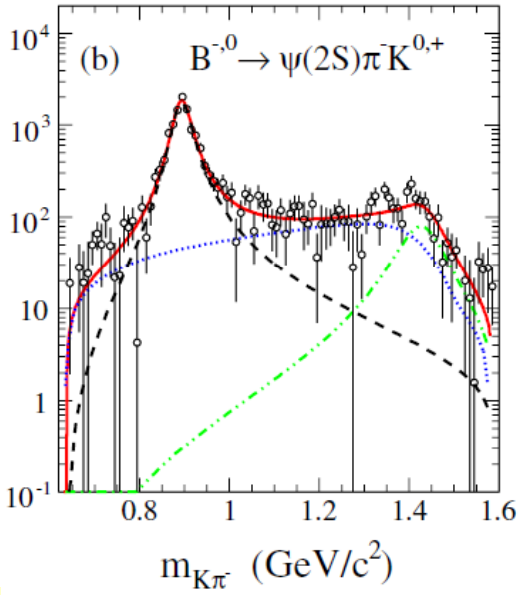


$M = 4433 \pm 4 \pm 2$ MeV/c^2
$\Gamma_{tot} = 45^{+18}_{-13}{}^{+30}_{-13}$ MeV
Nsig = 121 ± 30 evts
χ^2/dof = 80.2/94.0 6.5 σ

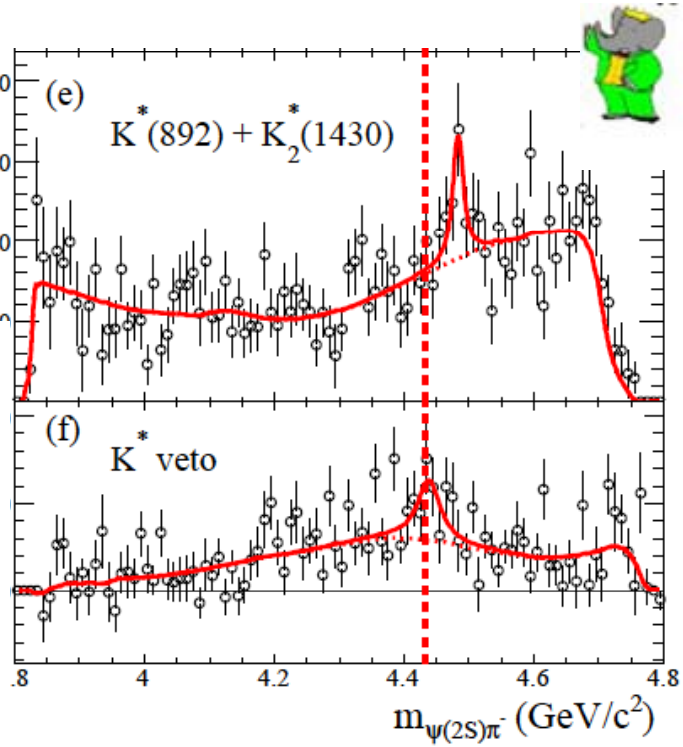
Very serious tetraquark candidate

$B \to \psi(2S)\,\pi^{\pm} K$
B & K --- charged or neutral

BaBar's Fits
K*'s and Z(4430)
in the Dalitz plane



BaBar, PRD 79, 112001 (2009)



BaBar's "Belle-like" analysis --- ~1.9σ

$BF(B^0 \to Z^+K) \times BF(Z^+ \to \psi(2S)\pi^+) < 3.1 \times 10^{-5}$ (@95% CL)
No conclusive evidence for $Z(4430)^+$

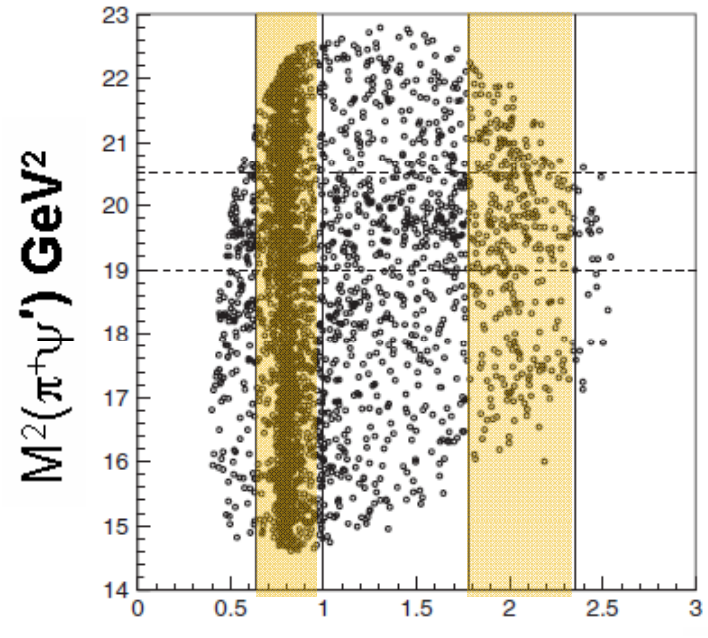
Belle's Dalitz Analysis

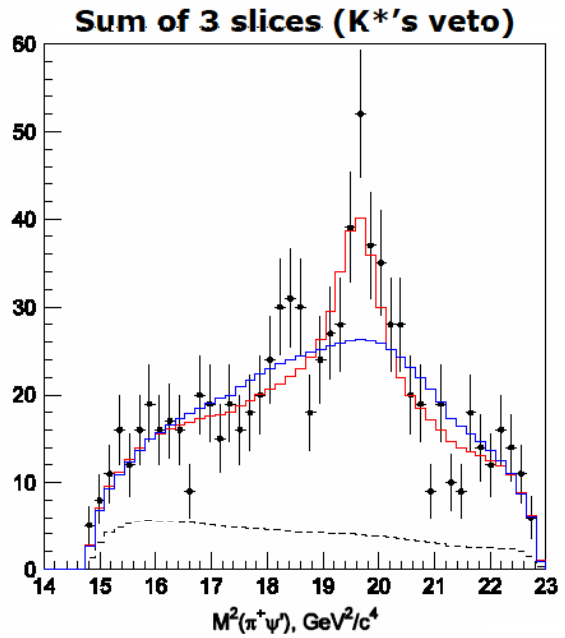
K*s included in the analysis:
κ, K*(892), K*(1410), $K^*_0(1430)$, $K^*_2(1430)$, K*(1680)

605 fb^{-1}

Belle, PRD 80,031104 (R)(2009)

Belle confirms the original result of Z(4430) with 6.4σ





$$M = 4443^{+15\,+19}_{-12\,-13}\ \mathrm{MeV}/c^2$$

$$\Gamma = 107^{+86\,+74}_{-43\,-56}\ \mathrm{MeV}$$

The width gets larger than the original, although the uncertainty is large

Fit with Z

$$\mathbf{BF(\overline{B}^0 \to Z^+K) \times BF(Z^+ \to \psi(2S)\pi^+) = (3.2^{+1.8+\,5.3}_{-0.9\,-1.6}) \times 10^{-5}}$$

X(3940)
Y(3940)
Z(3930)

The X,Y,Z near 3940 MeV

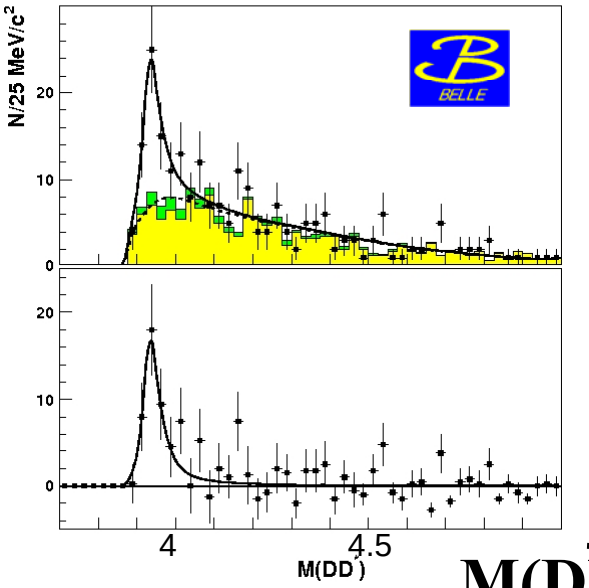
not seen in $\omega J/\psi$ → **X(3940)**

probably different

not seen in DD^* → **Y(3940)**

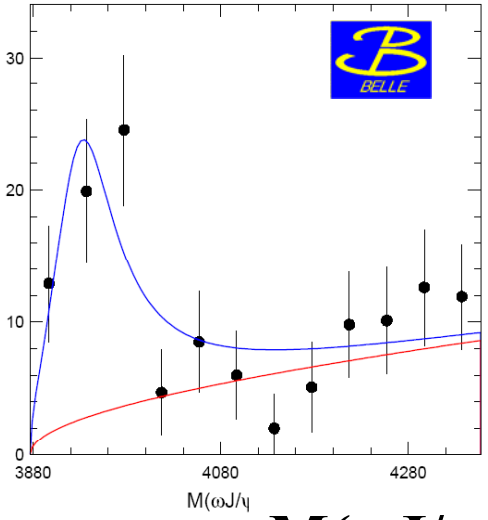
Probably the χ_{c2}' → **Z(3930)**

$e^+e^- \to J/\psi\, D\bar{D}^*$



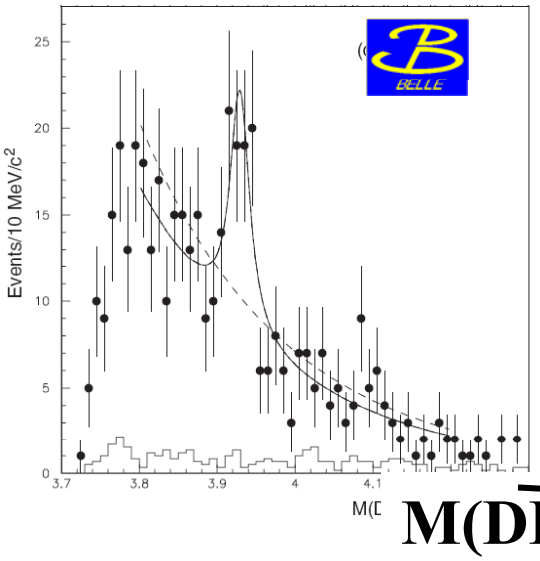
$M(D\bar{D}^*)$

$B \to \omega\, J/\psi\, K$



$M(\omega J/\psi)$

$\gamma\gamma \to D\bar{D}$



$M(D\bar{D})$

M = 3942 $^{+7}_{-6}$ ± 6 MeV

Γ_{tot} = 37 $^{+26}_{-15}$ ± 12 MeV

Nsig =52 $^{+24}_{-16}$ ± 11evts

PRL 100, 202001 (2008)

M=3943 ± 11 ± 13 MeV

Γ= 87 ± 22 ± 26 MeV

PRL94, 182002 (2005)

M = 3929 ± 5 ± 2 MeV

Γ_{tot} = 29 ± 10 ± 2 MeV

Nsig =64 ± 18evts

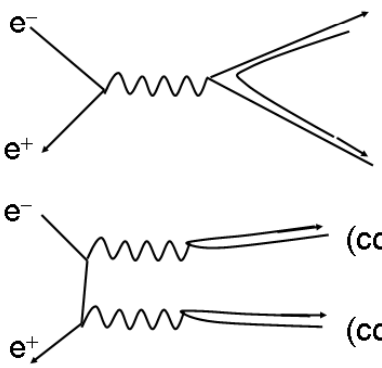
PRL 96, 082003 (2006)

X(3940) in Double charmonium production

Tag a J/ψ

Belle PRD 70, 071102 (2004)

Belle, PRL 98, 082001 (2007)



(cc) C-odd J/ψ

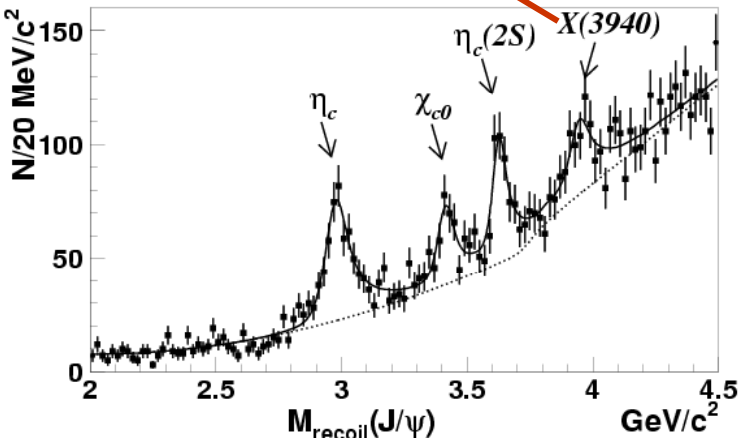
(cc̄)' C-even η_c, χ_c, X?

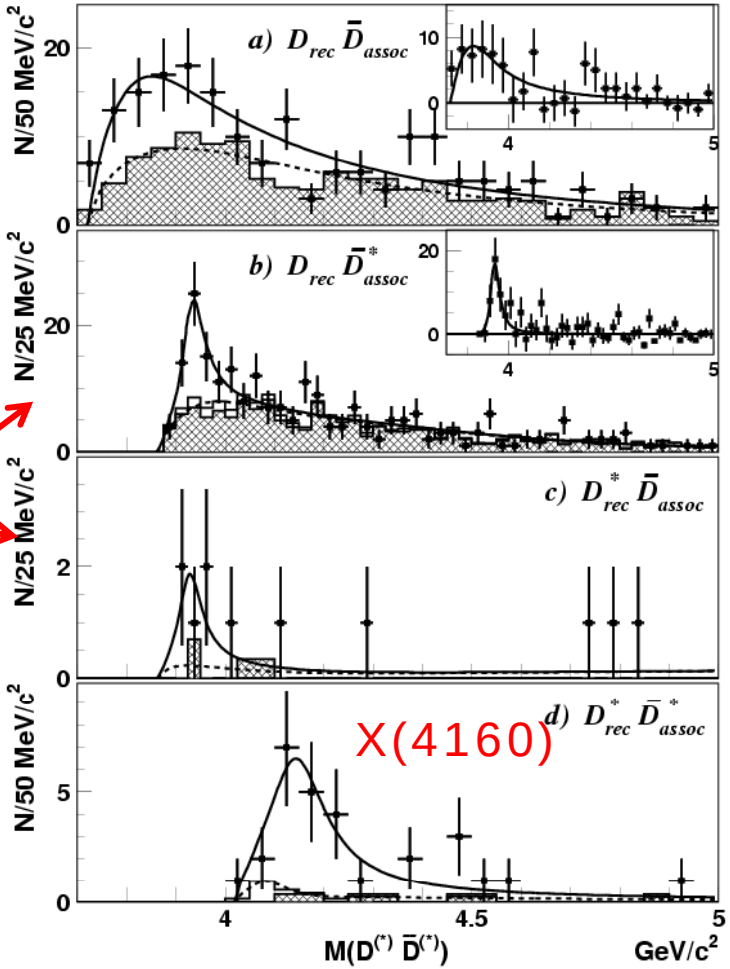
(cc) C-odd J/ψ

(cc)' C-odd X? (suppressed)

Recoil masses distribution

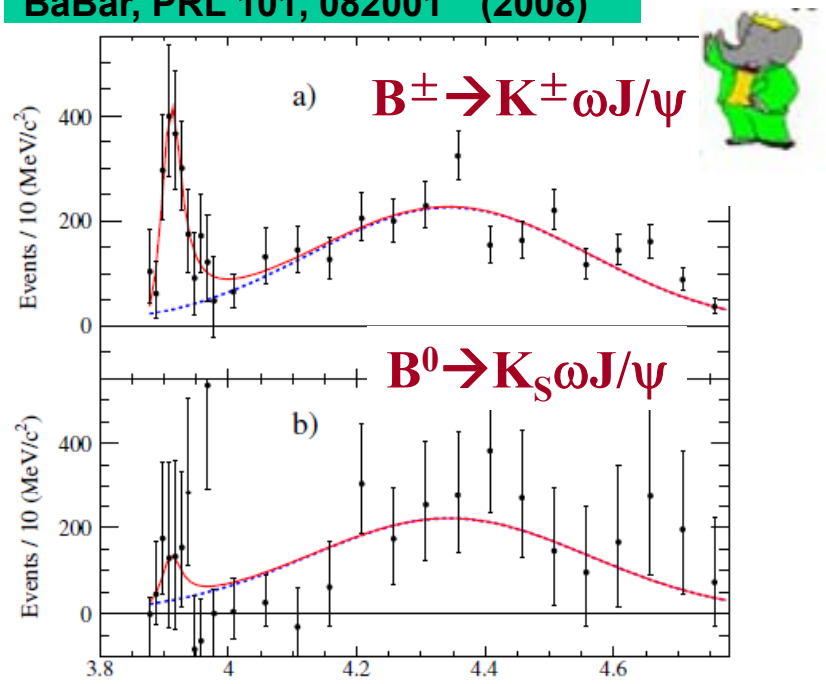
Here is X(3940) → DD̄*



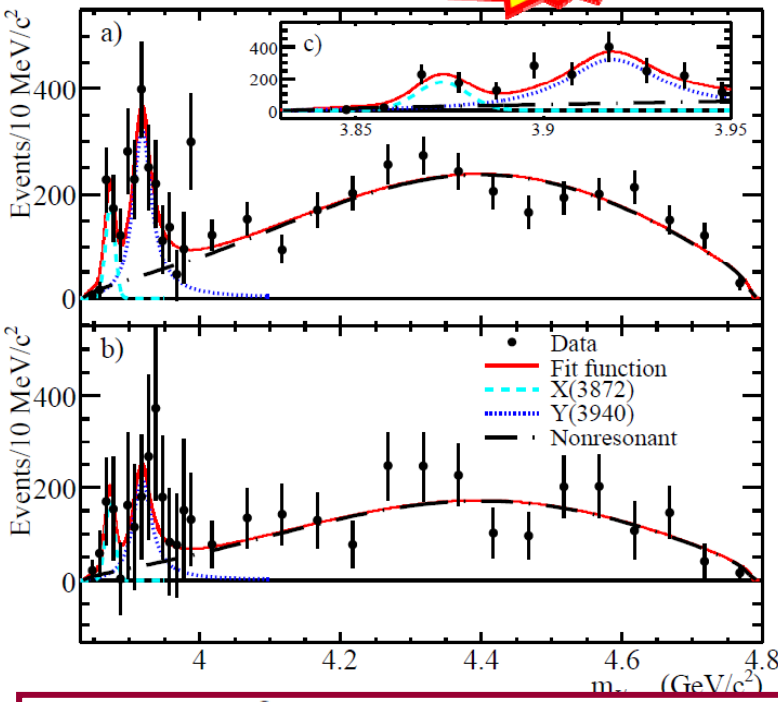


Y(3940)→ ωJ/ψ confirmed

BaBar, PRL 101, 082001 (2008)



BaBar, arXiv:1005.5190 Update **426 fb^{-1}**



	Mass (MeV)	Γ (MeV)
Belle 253 fb^{-1}	$3943 \pm 11(stat) \pm 13(syst)$	$87 \pm 22(stat) \pm 26(syst)$
BaBar 350 fb^{-1}	**$3914.6\ ^{+3.8}_{-3.4} \pm 2.0$**	**$34\ ^{+12}_{-8} \pm 5$**

$m_Y\,(\mathrm{MeV}/c^2) = 3919.1\ ^{+3.8}_{-3.4}(\mathrm{stat}) \pm 2.0(\mathrm{syst})$

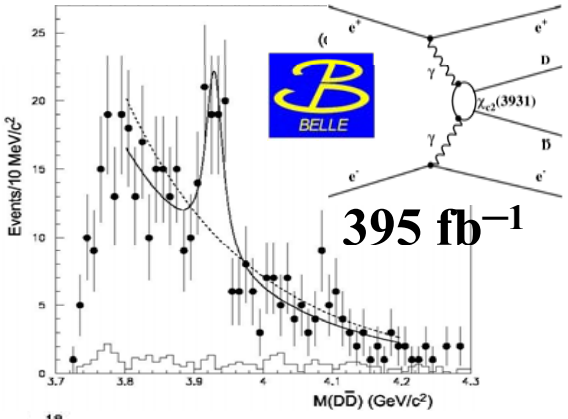
$\Gamma_Y\,(\mathrm{MeV}) = 31\ ^{+10}_{-8}(\mathrm{stat}) \pm 5(\mathrm{syst})$

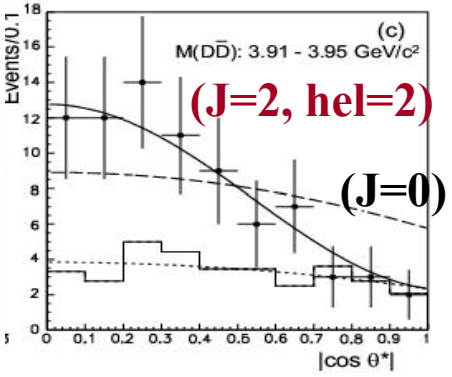
Comparing BF ratios, B(ωJ/ψ)/ B($D\bar{D}^*$), in the X and Y production processes X(3940) and Y(3940) are different sates

Belle, PRD 81, 031103(R) (2010)

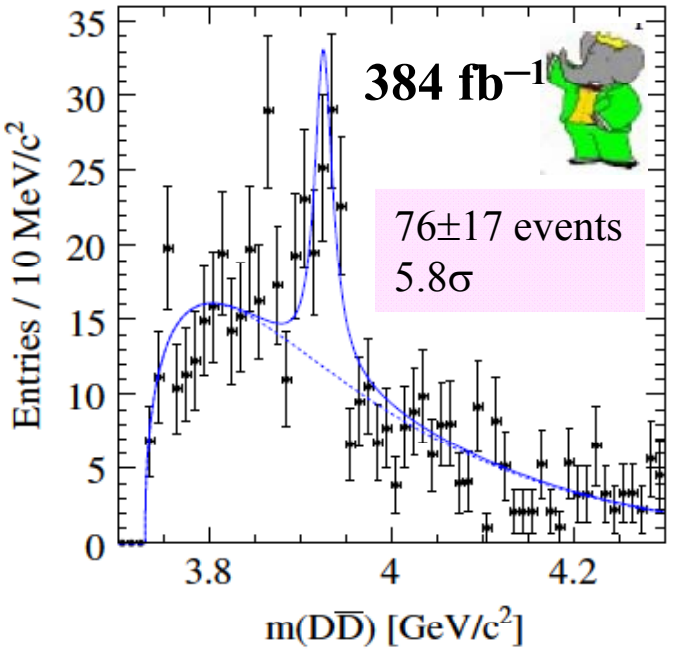
$\gamma\gamma \rightarrow Z(3930) \rightarrow D\bar{D}$ confirmed

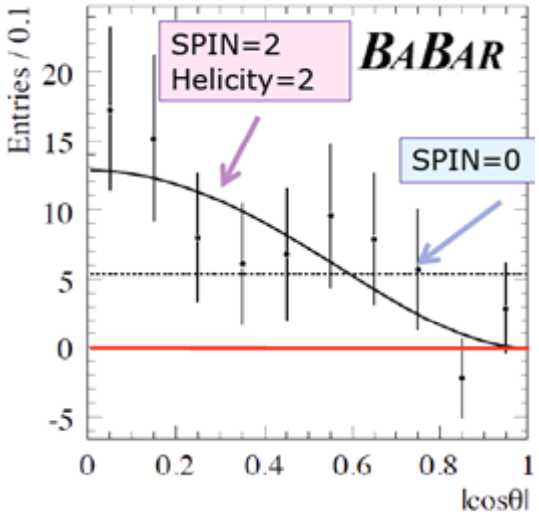
Belle PRL 96, 082003 (2006)





BaBar, PRD 81, 092003 (2010)





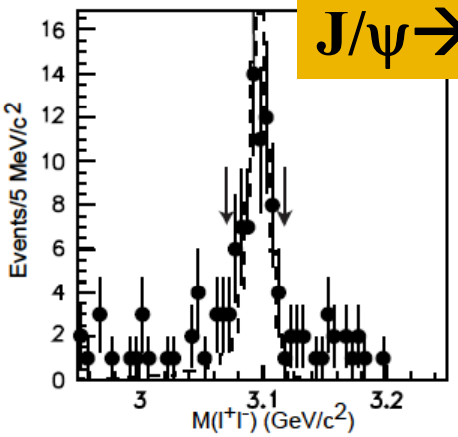
m(3930)=3926.7±2.7±1.1 MeV/c^2
Γ(3930)=21.3±6.8±3.6 MeV
$\Gamma_{\gamma\gamma}$·BF(Z(3930→DD̄)=0.24±0.05±0.04 keV

BELLE
m(3930)=3929±5±2 MeV/c^2
Γ(3930)=29±10±2 MeV
$\Gamma_{\gamma\gamma}$·BF(Z(3930→DD̄))=0.18 ±0.05±0.03 keV

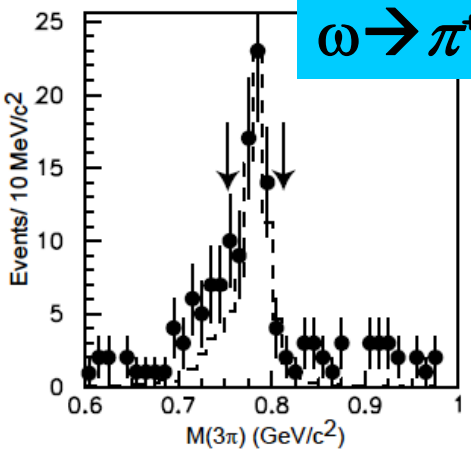
Belle and Babar results are consistent

Confirms that Z(3930) = $\chi_{c2}(2P)$

Peak in $\gamma\gamma \rightarrow \omega J/\psi$

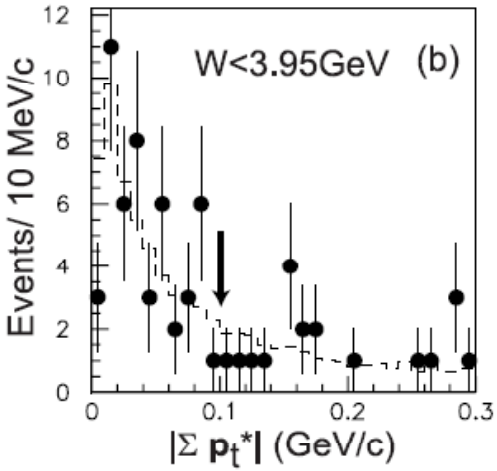


$J/\psi \rightarrow l^+l^-$

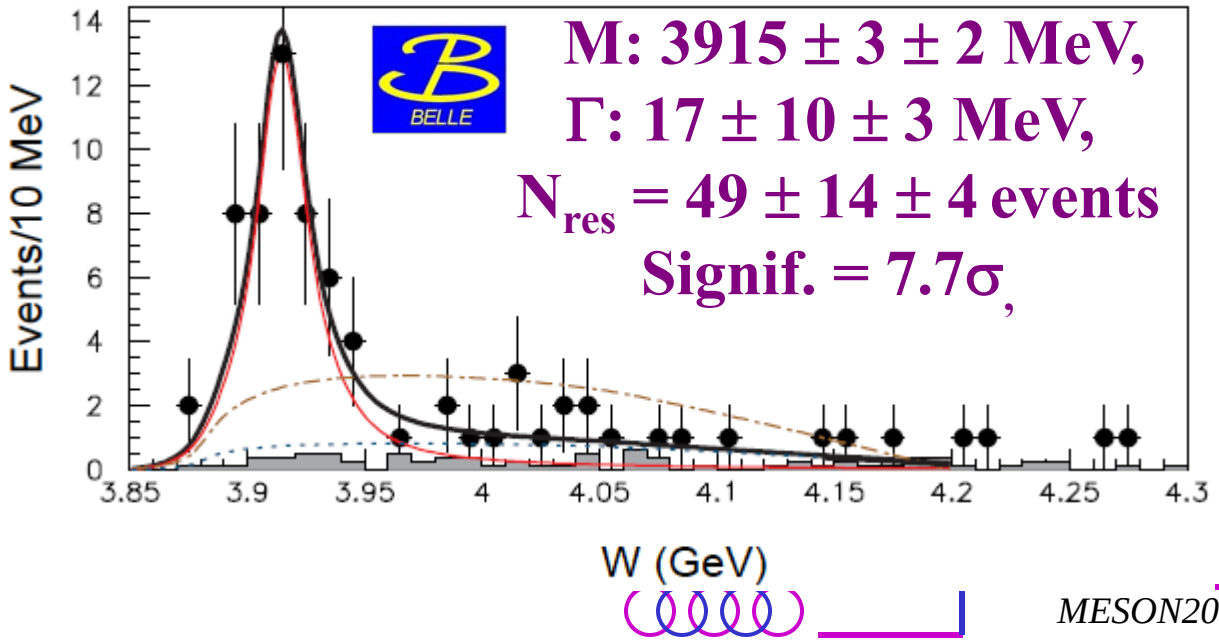


$\omega \rightarrow \pi^+\pi^-\pi^0$

Belle, PRL 104, 092001 (2010)



694 fb^{-1}



M: 3915 ± 3 ± 2 MeV,
Γ: 17 ± 10 ± 3 MeV,
N_{res} = 49 ± 14 ± 4 events
Signif. = 7.7σ,

Two-photon production of Y(3940)?

or

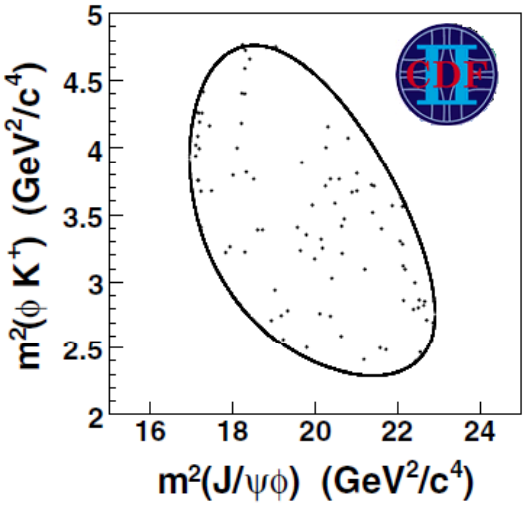
New decay mode of Z(3930)/χ_{c2}(2P)?

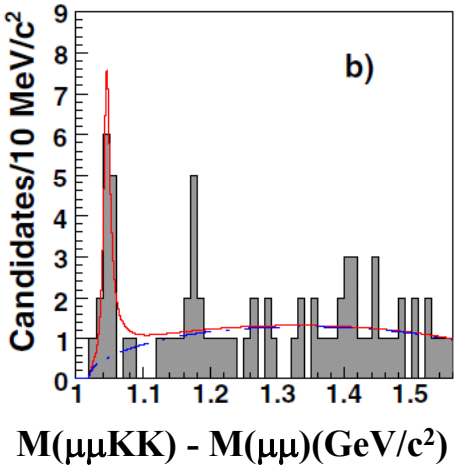
Y(4140)
X(4350)

Y(4140)→ φ J/ψ

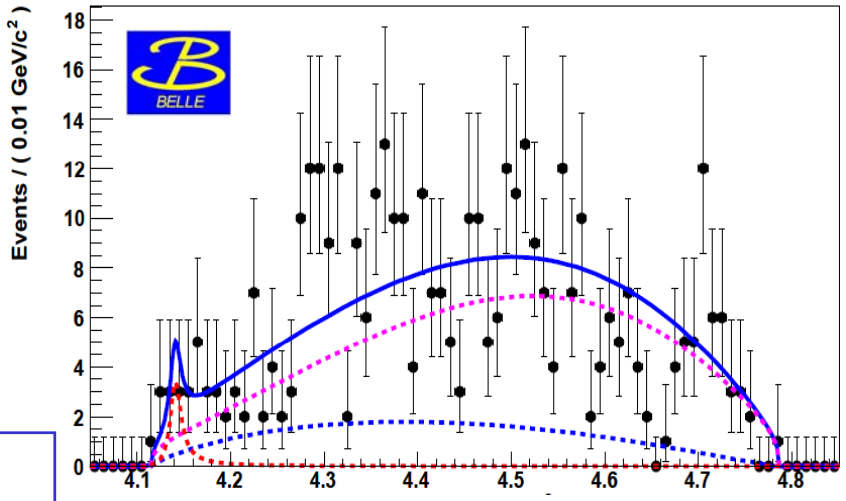
CDF observed new charmonium-like particle

CDF, PRL 102, 242002 (2009)





Belle, Lepton-Photon 2009



$B^+ \to J/\psi\ \phi\ K^+$

14 ± 5 events (3.8σ)
from 2.7 fb^{-1}

CDF

M = 4143.0 ±2.9 ±1.2 MeV/c^2

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

Belle Preliminary

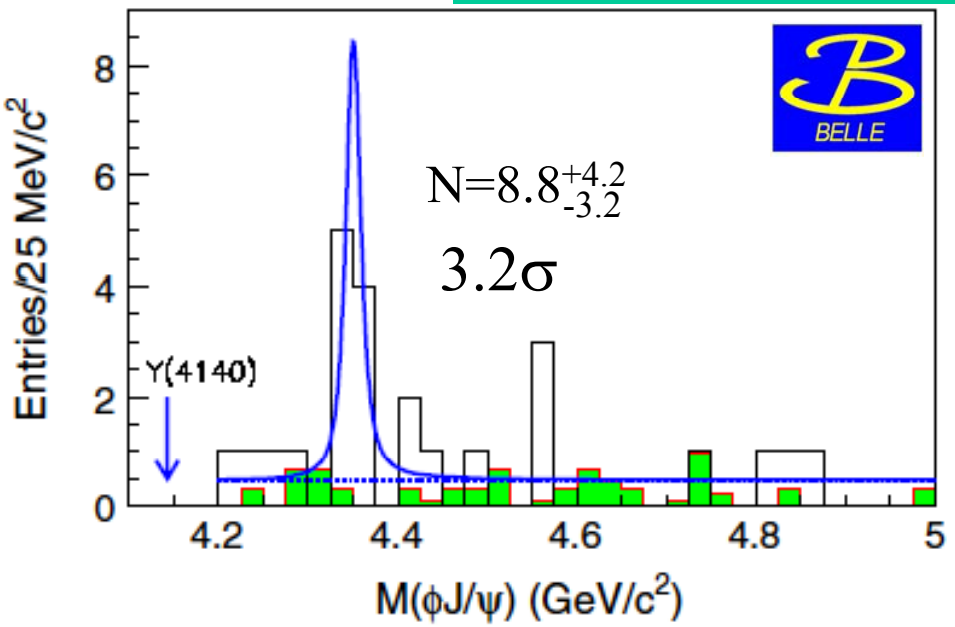
BF(B→YK)BF(Y→J/ψφ)
$< 6 \times 10^{-6}$ (@90%CL)

Ds* $\overline{\text{Ds}}$* molecule or tetraquark ?

Search in γγ process

Belle, PRL 104,112004 (2010)

$\gamma\gamma \rightarrow \phi\, J/\psi$

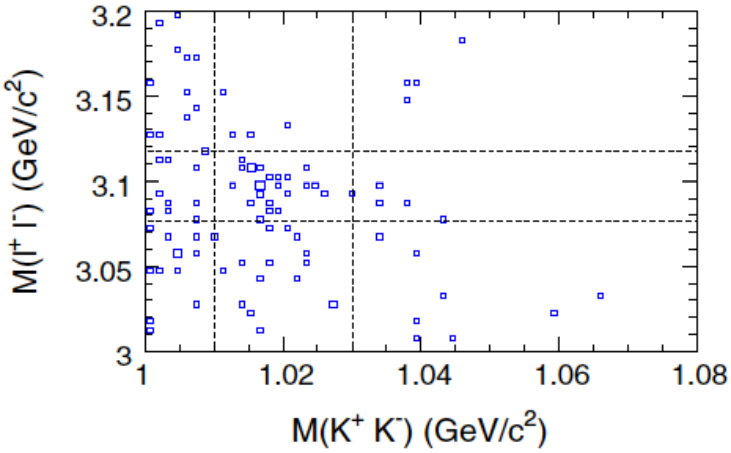


Belle: Y(4140) not seen in two-photon process

Instead, a **new peak** is seen at around 4.35 GeV in $\gamma\gamma \rightarrow \phi\, J/\psi$

$M = 4350.6\ ^{+4.6}_{-5.1} \pm 0.7$ MeV/c²

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



Wai Upsilon

Υ_b and $\Upsilon(5S)$

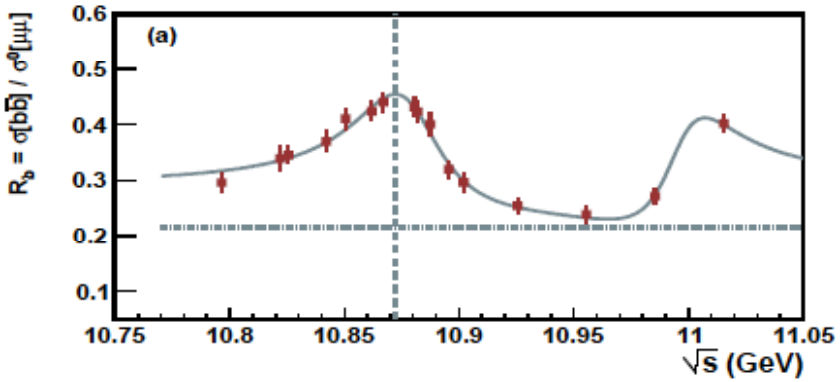
Large "Y (5S)" → Y (nS) $\pi^+\pi^-$, or Y_b

Y (5S) → Y (nS) $\pi^+\pi^-$

Belle, PRL 100, 112001 (2008)

Process	Γ (MeV)
"Y(5S)"→Y(1S)ππ	$0.59 \pm 0.04 \pm 0.09$
"Y(5S)"→Y(2S)ππ	$0.85 \pm 0.07 \pm 0.16$
"Y(5S)"→Y(3S)ππ	$0.52 \pm {}^{0.20}_{0.17} \pm 0.10$

Then, the energy scan
DONE in 2007 by Belle



Much larger than
Γ(Y(4S) →Y(nS)ππ) ~ O(1keV)

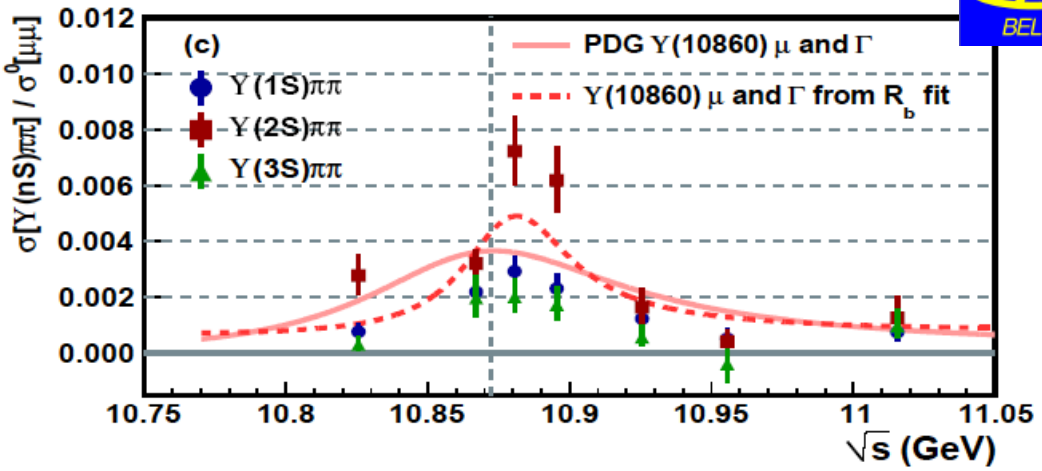
Y (5S) peak from the Belle measurement
mass= 10879 ± 3 MeV/c^2
width $=46\ {}^{+9}_{-7}$ MeV

A possible explanation:

another state Y_b
decaying → Y(nS)ππ

Energy scan of $e^+e^- \to \Upsilon(nS)\pi^+\pi^-$

Belle, ArXiv 0808.2445v2, submitted to PRL



Fit $\Upsilon(nS)\pi^+\pi^-$ with $\Upsilon(5S)$ parameters
--- poor agreement

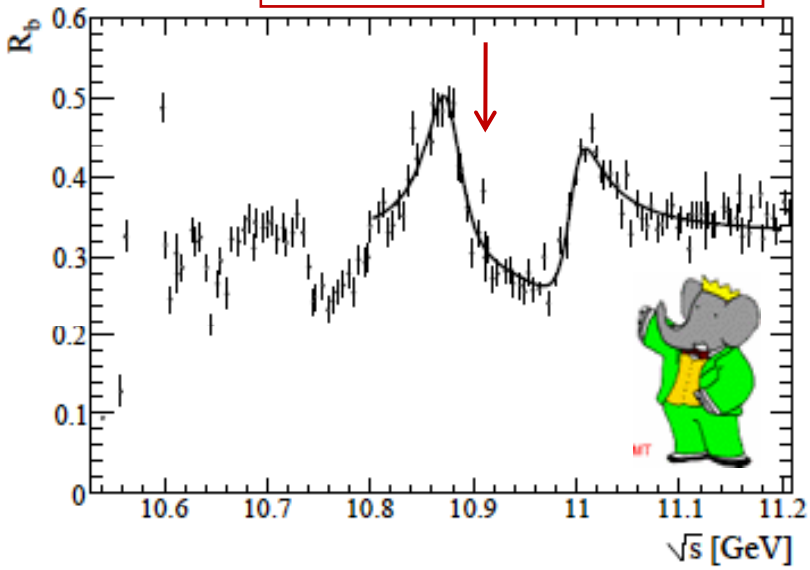
because of Y_b ?

$M = 10888.4\ ^{+2.7}_{-2.6} \pm 1.2$ MeV/c^2
$\Gamma = 30.7\ ^{+8.3}_{-7.0} \pm 3.1$ MeV
($\Delta M = 9 \pm 4$ MeV/c^2)

BaBar, PRL 102, 012001 (2009)

Babar's energy scan
$b\bar{b}$ cross section

This structure may be related to Y_b by A.Ali et al. PLB 684, 28 (2010)



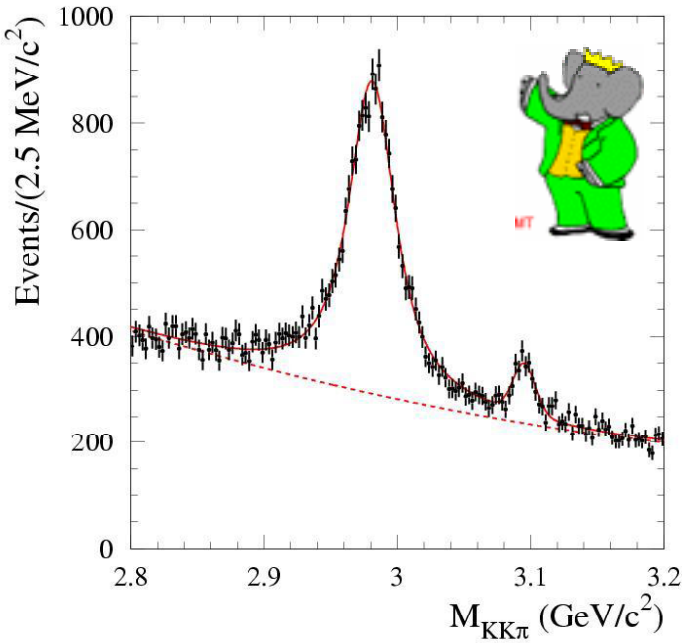
η_c, η_b and Y(1D)

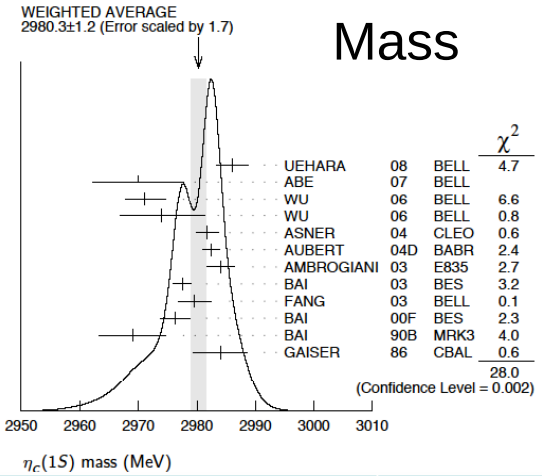
η_c properties from two-photon production

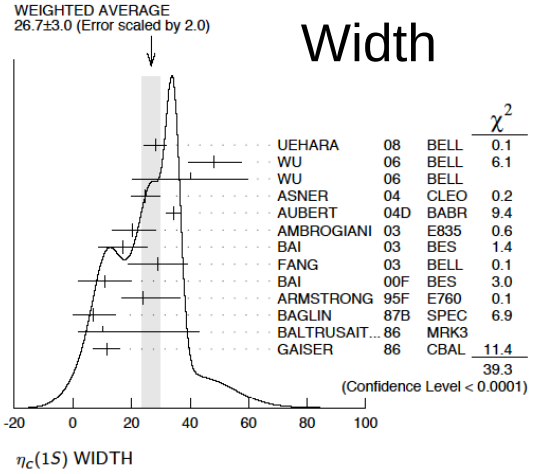
$\gamma\gamma \rightarrow \eta_c \rightarrow K_S K^+\pi^-$ No-tag mode

BaBar, PRD 81, 052010 (2010)

N = 14450 ± 320 ± 400 events







	Mass, MeV	Width,MeV
PDG	2980.3±1.2	26.7±3.0
BABAR(88 fb^{-1})	2982.5±1.1±0.9	34.3±2.3±0.9
BABAR(470 fb^{-1}),	2982.2±0.4±1.6	31.7±1.2±0.8

BABAR : $\Gamma(\eta_c \rightarrow \gamma\gamma)B(\eta_c \rightarrow K\bar{K}\pi)$ = 0.374±0.009±0.031 keV

PDG: 0.44±0.04 keV, CLEO: 0.407±0.022±0.028 keV

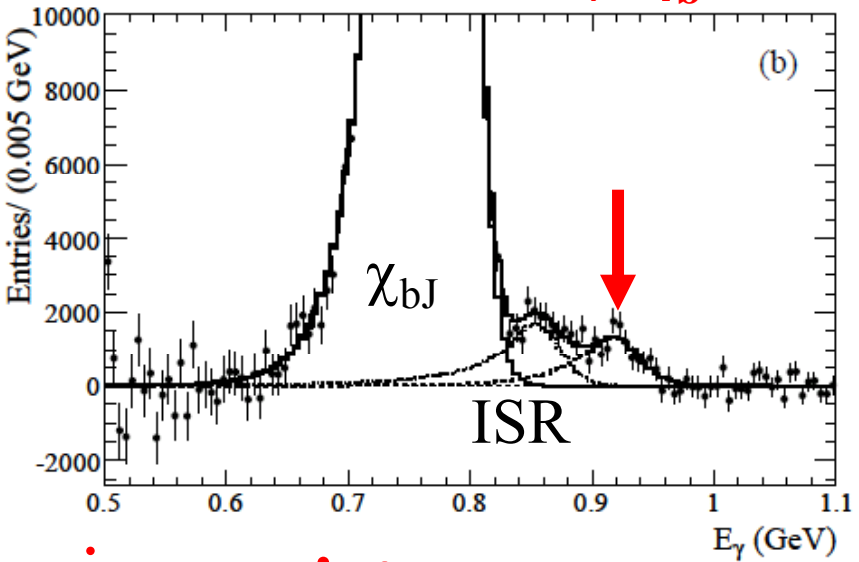
Discovery of η_b state

- η_b observed by BaBar in 2008

in rare decays of Υ(2S) and Υ (3S)

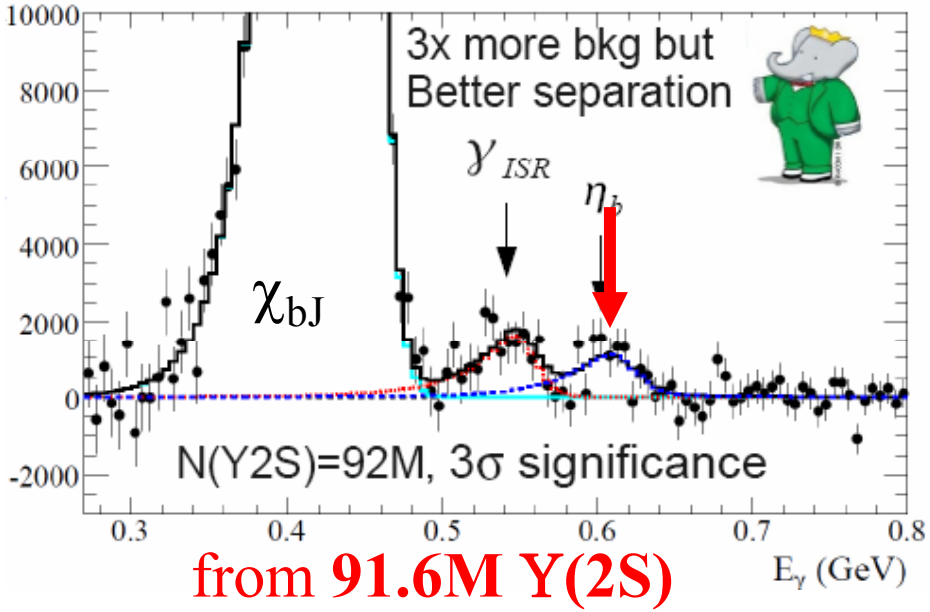
BaBar, PRL 101, 071801 (2008)

$\Upsilon(3S) \rightarrow \gamma\, \eta_b$



BaBar, PRL 103, 161801 (2009)

$\Upsilon(2S) \rightarrow \gamma\, \eta_b$



η_b is seen: from **109M Υ(3S)**

19 k ± 2k (10σ)

M=9388.9 $\pm \,^{3.1}_{2.3}$ ± 2.7 MeV

from **91.6M Υ(2S)**

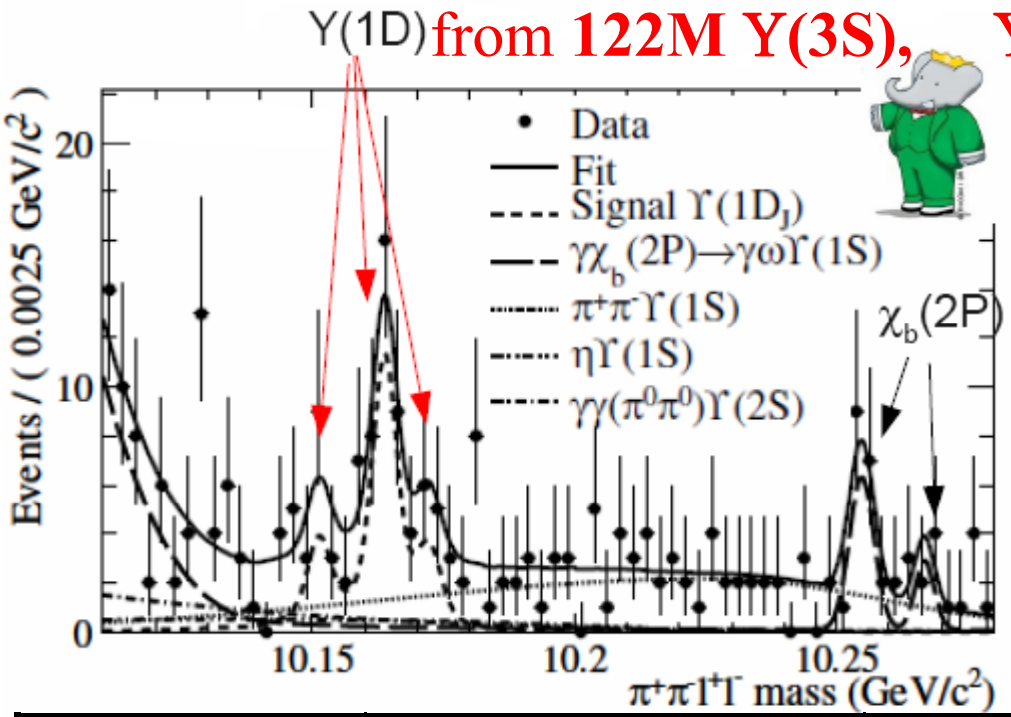
12.8 k ± 3.5k (3.7σ)

M=9394.2 $\pm \,^{4.8}_{4.9}$ ± 2.0MeV

Combined: **Hyperfine mass splitting (1S) = 69.5 ± 3.2 MeV/c^2**

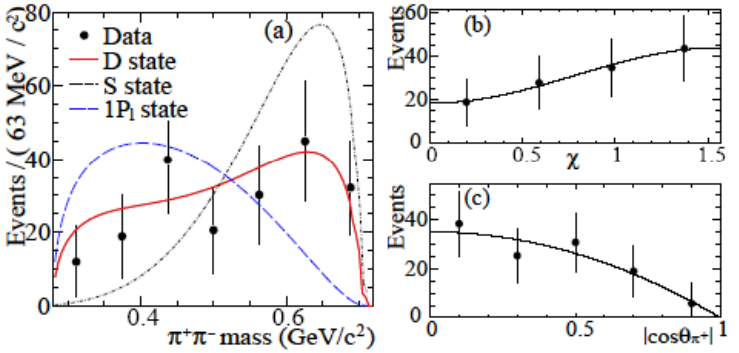
Observation of Y (1D) → $\pi^+\pi^-$ Y (1S)

Y(1D) from **122M Y(3S), Y(3S) → γγ Y(1D)**



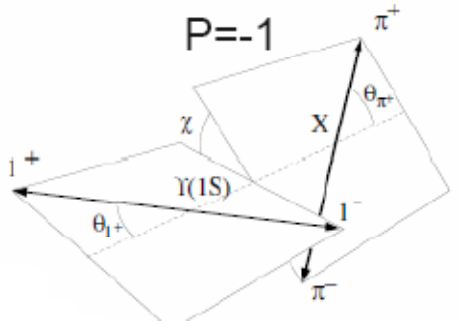
$n\ ^{2S+1}L_J$	Mass (MeV/c^2)	
Y ($1\ ^3D_1$)	$10151.6 \pm {}^{1.3}_{1.4} \pm 0.5$	
Y ($1\ ^3D_2$)	$10164.5 \pm 0.8 \pm 0.5$	6.2 σ
Y ($1\ ^3D_3$)	$10172.9 \pm 1.7 \pm 0.5$	

BaBar, ArXiv 1004.0175, Submitted to PRL



L=2

P=-1



CLEO (2004) in γγ Y (1S)

$10161.1 \pm 1.6 \pm 0.6$ MeV/c^2

Summary

Recent updates and New Topics:

X(3872) : No mass splitting, production / decay modes

→ $\psi(2S)\gamma$ seen at BaBar, not seen at Belle

→ $\omega J/\psi$ confirmed

Z(4430): No evidence from BaBar

Confirmation with the Dalitz analysis by Belle

Y(3940): Updated analysis

Z(3930) : confirmed : Z(3930) = $\chi_{c2}(2P)$

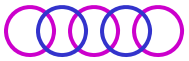
CDF's new particle Y(4140) → $J/\psi\phi$, not seen at Belle

New structures seen in two-photon processes, $\gamma\gamma \rightarrow J/\psi\omega$ and $J/\psi\phi$

Y(5S) and Y_b, an exotic candidate with similar masses ?

Precise measurement of the η_c mass and width in $\gamma\gamma$

New decay mode $Y(1D) \rightarrow Y(1S)\pi^+\pi^-$ found

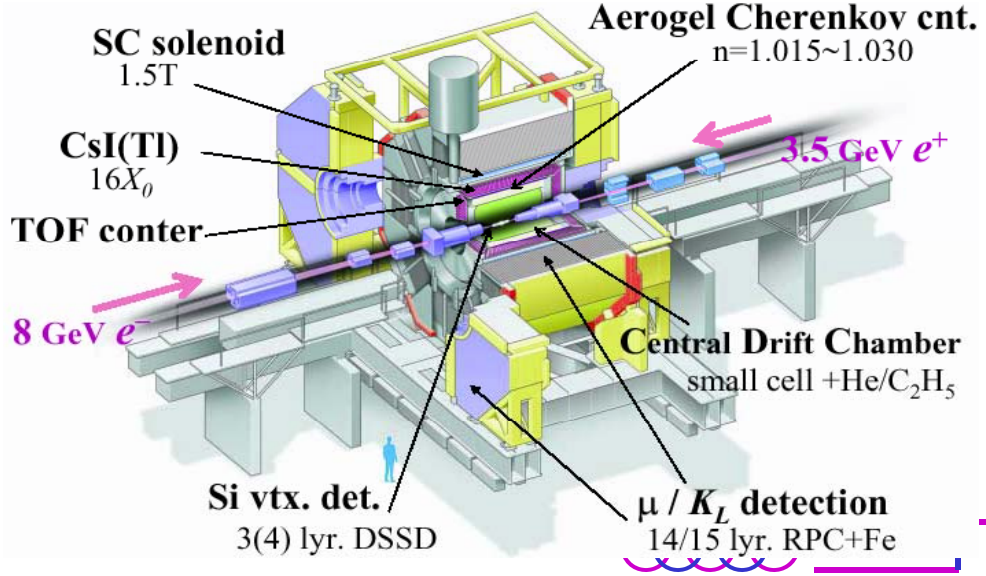


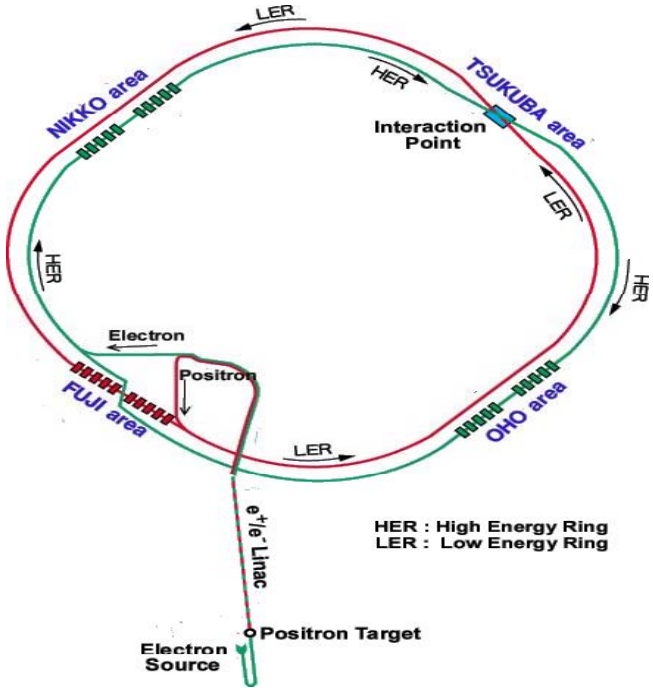
Backup slides

KEKB Accelerator and Belle Detector

- Asymmetric e^- e^+ collider
  8 GeV e- (HER) x 3.5 GeV e+ (LER)
  $\sqrt{s}$=10.58 GeV $\Leftrightarrow$ Υ(4S)
  Beam crossing angle: 22mrad
- Continuous injection
- Luminosity
  $L_{max}=2.1\times10^{34}\ cm^{-2}s^{-1}$

$\int Ldt \sim$ 1000 fb^{-1} (Jun.2010)



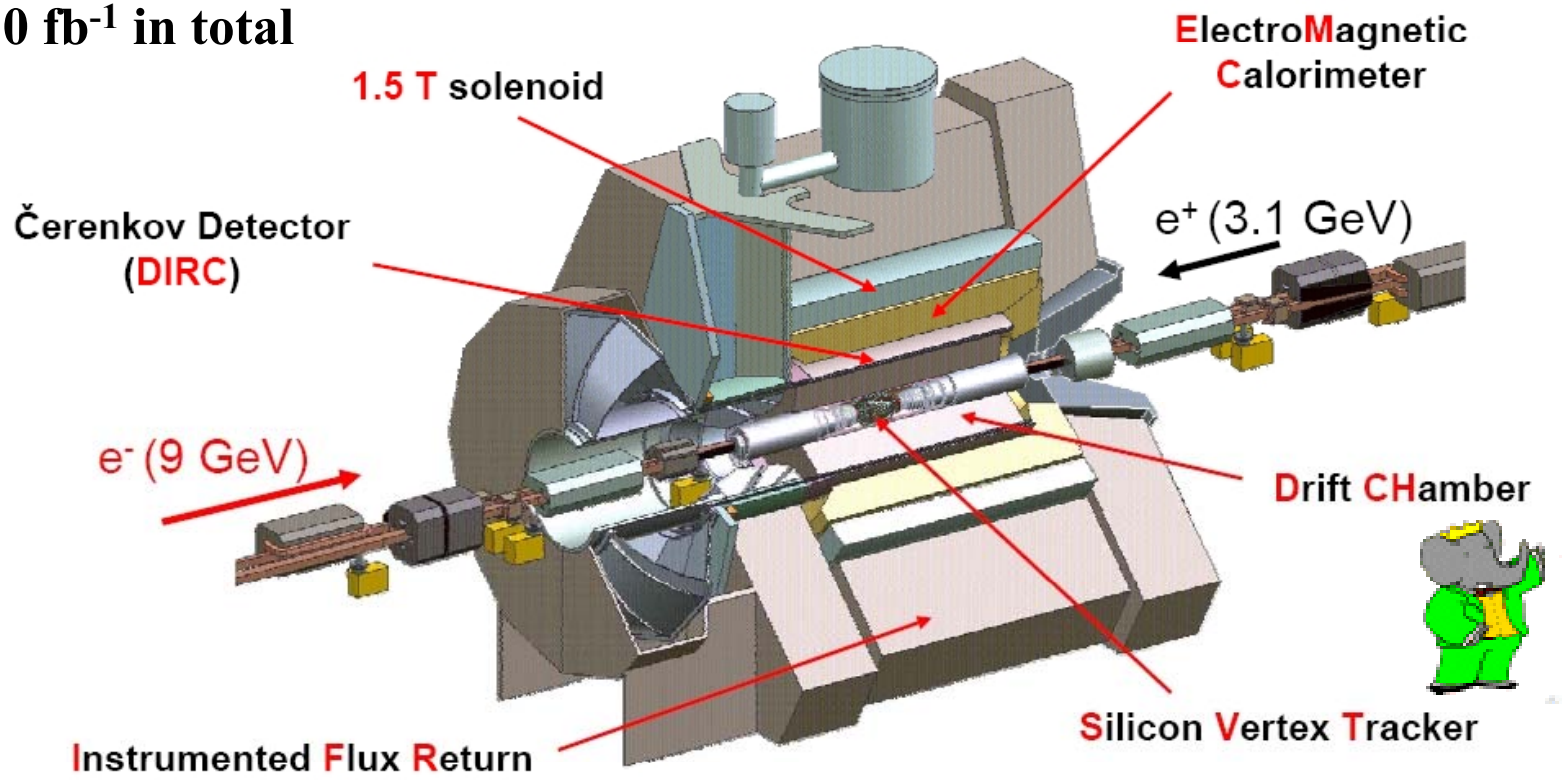


High momentum/energy resolutions
CDC+Solenoid, CsI
Vertex measurement – Si strips
Particle identification
TOF, Si-aerogel, CDC-dE/dx,
RPC for K_L/muon

BaBar at PEP-II

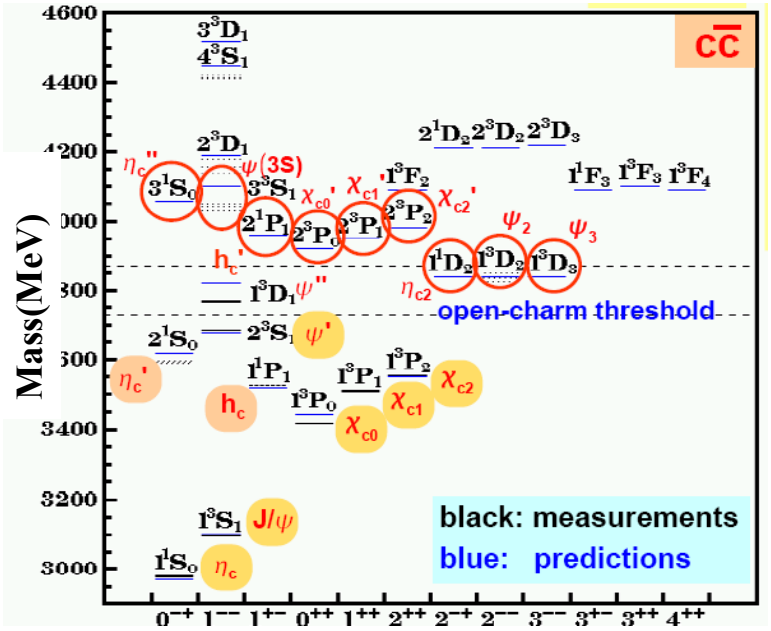
$e^+e^- \rightarrow Y(4S)$ and nearby continuum: $E_{cms} \sim 10.6$ GeV

530 fb^{-1} in total



List of new particles of heavy quarkonia

Sequences of ordinary charmonia



J^{PC}

Ordinary-like charmonium

$\eta_c(2S)$ $Z(3930)=\chi_{c2}(2P)$

No clear charmonium assignment

Double charmonium production

X(3940) X(4160)

Decays with ψ(or ψ')

X(3872) Y(4008)

Y(4260) Y(4320)

Y(3940) Y(4664)

Y(4140) and more …?

Decays with $\psi'(\chi_{c1})$ and Charged

$Z(4430)^+$ $Z_1(4058)^+$

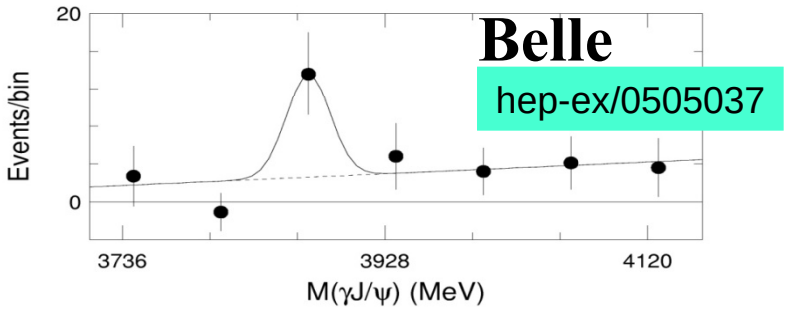
$Z_2(4258)^+$

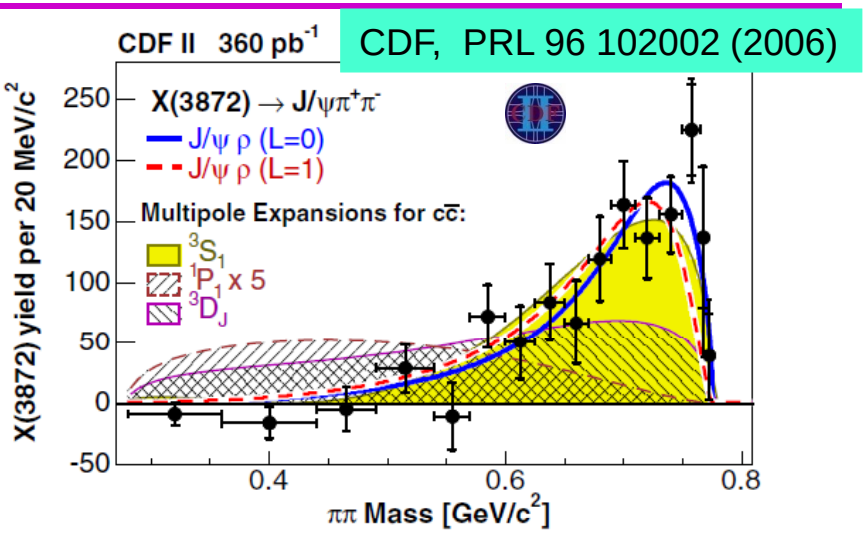
Bottomonium(like) states

η_b, Y(1D), and Y_b

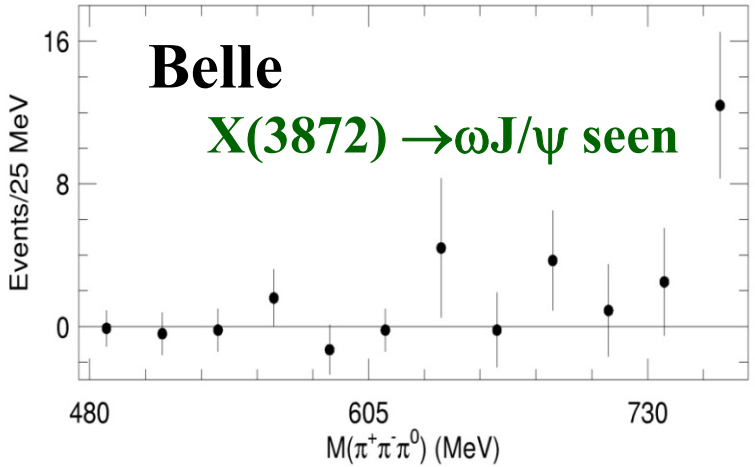
C=+ is established for X(3872)

X(3872) → γJ/ψ seen C-even
(in contrast to non-obs. of $\gamma\chi_c$)





$\Gamma(X\to\gamma J/\psi)/\Gamma(X\to\pi^+\pi^- J/\psi) = 0.14\pm0.15$ A small radiative width –unlikely for χ'_c



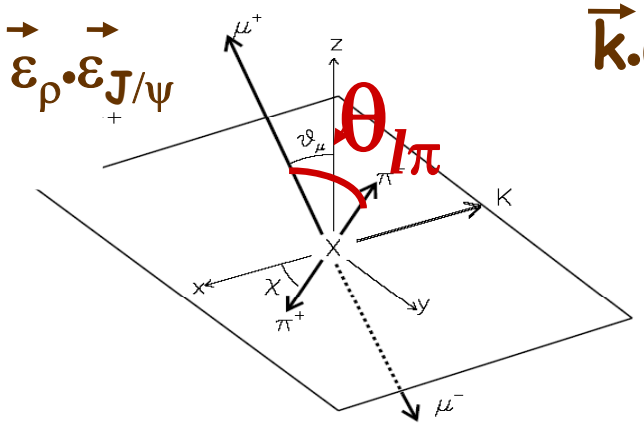
Even parity is favored from the ππ invariant mass distribution (ρ-type ππ)

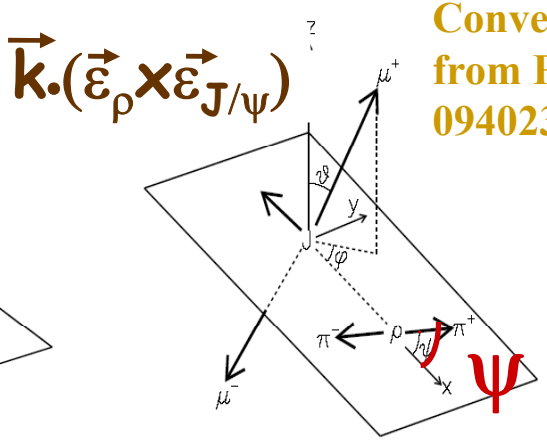
Indication of isospin non-conservation

Angular analysis of $l^+l^-\pi^+\pi^-$

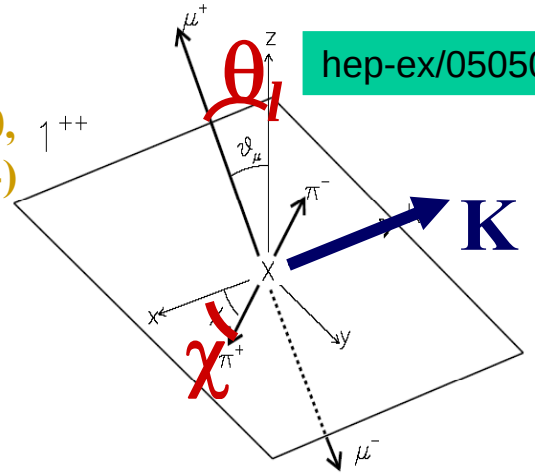
$J^P = 1^+$ is favored **(Belle/ CDF)**

Spin-parity of X(3872); 0^+, 0^- or 1^+?

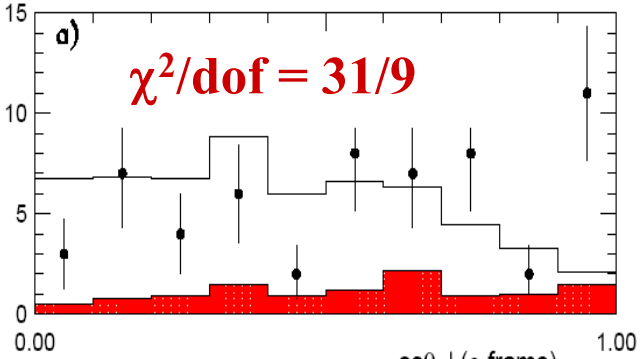


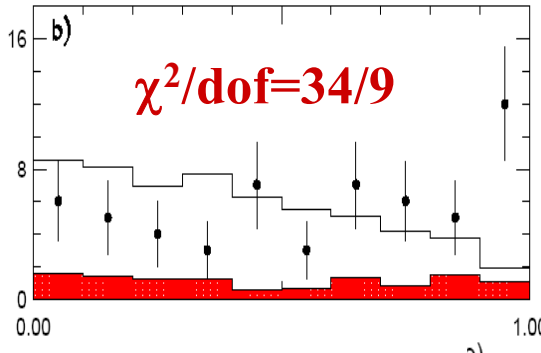


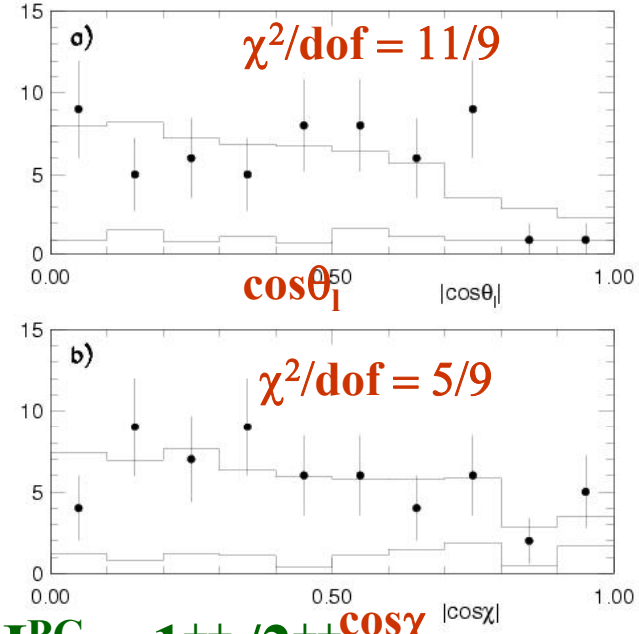
Convention from PRD 70, 094023 (2004)



hep-ex/0505038



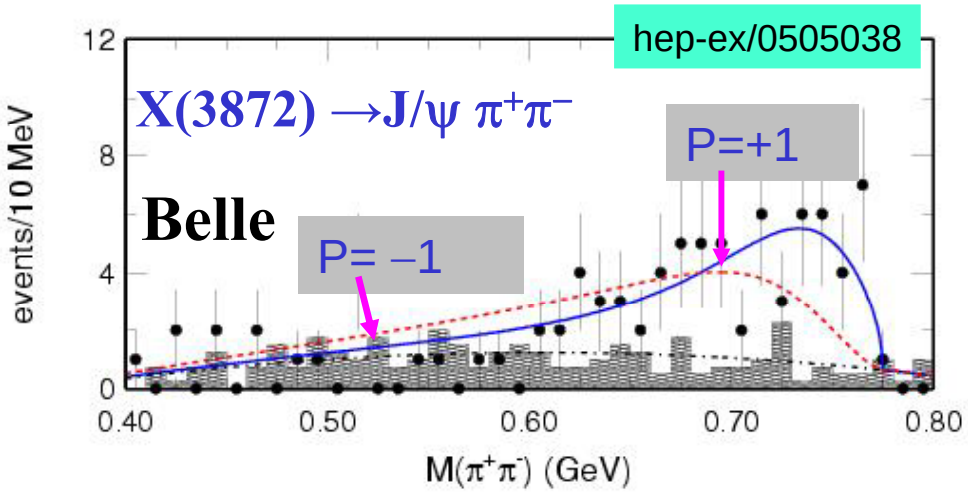




rule out 0^{++} & 0^{-+}

X(3872) in B-decay ⇛ $J^{PC} = 1^{++}/2^{++}$

Spin-parity of X(3872); 0^+, 0^- or 1^+?



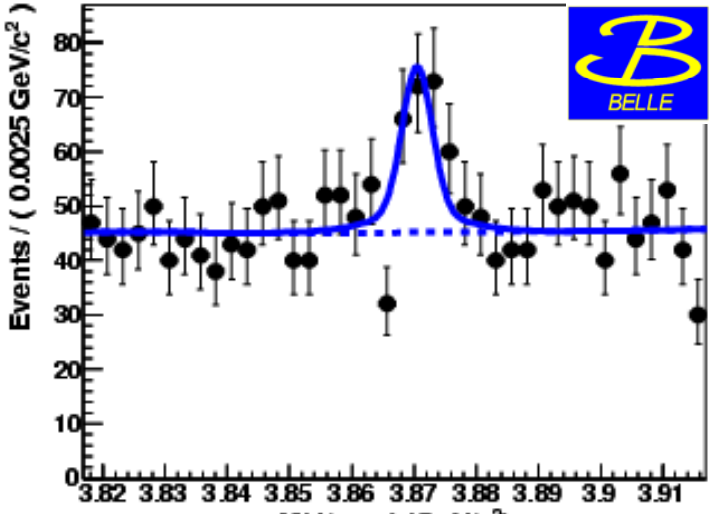
New production mode

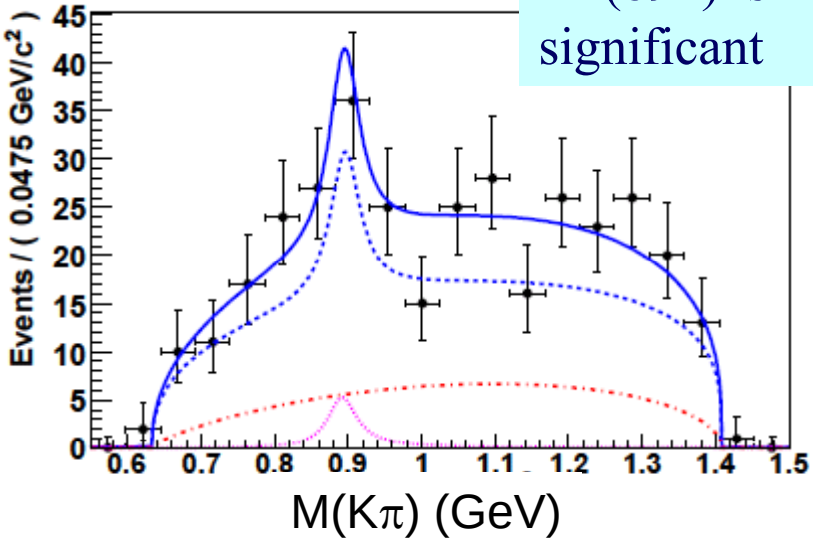
Belle, Arxiv:0809.1224

$B^0 \to X(3872)(K^+\pi^-)_{\text{Non-Res}}$ observed

605 fb^{-1}

K*(892) is not significant



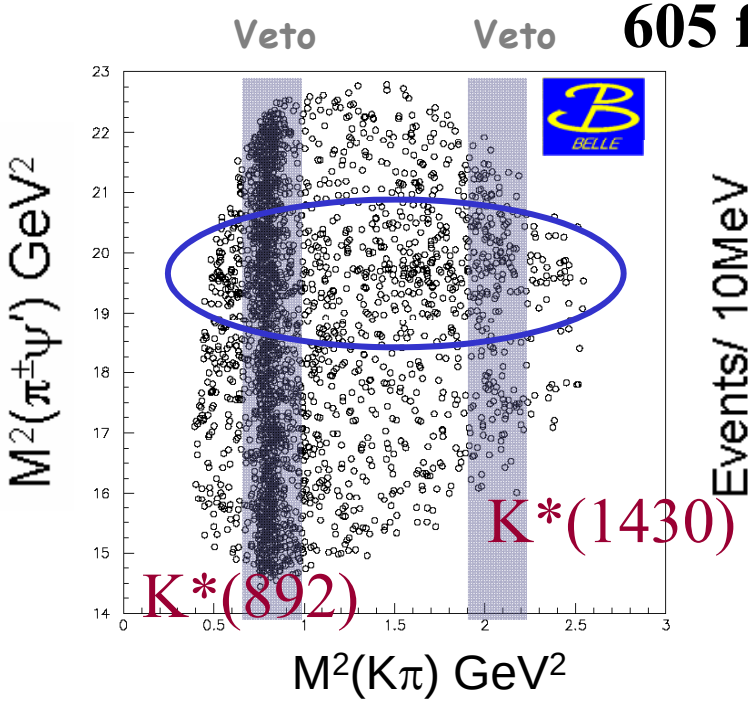


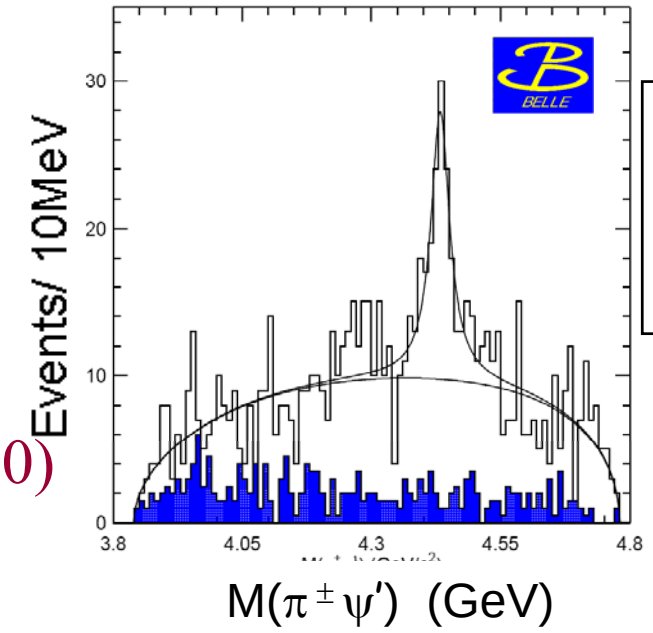
$BF(B^0 \to X(K^+\pi^-)_{NR})\, BF(X \to J/\psi\, \pi^+\pi^-) = (8.1 \pm 2.0\ ^{+1.1}_{-1.4}) \times 10^{-6}$

$BF(B^0 \to X\, K^{*0})\, BF(X \to J/\psi\, \pi^+\pi^-) < 3.4 \times 10^{-6}$ (90% CL)

K* is not significant, in contrast to $B^0 \to (J/\psi, \psi')K^*$ decays etc.

$Z(4430)^+$: Charged charmonium-like state





PRL 100, 142001 (2008)

$M = 4433 \pm 4 \pm 2$ MeV/c^2
$\Gamma_{tot} = 45\ ^{+18\ +30}_{-13\ -13}$ MeV
Nsig $= 121 \pm 30$ evts
χ^2/dof $= 80.2/94.0$ 6.5 σ

Close to
$M(D^*)+M(D_1(2420)) = 4433 \pm 1$ MeV/c^2,
$\Gamma(D_1) = 20$MeV

$B \to \psi(2S)\pi^{\pm}K$ ($\psi' \equiv \psi(2S)$) , $\psi' \to l^+l^-$, $J/\psi\ \pi^+\pi^-$
B and K --- charged or neutral

$BF(\bar{B}^0 \to Z^+K) \times BF(Z^+ \to \psi(2S)\pi^+) = (4.1 \pm 1.0 \pm 1.4) \times 10^{-5}$

Veto the M(Kπ) regions of K*(892) and K*(1430)

Enhancement at M(πψ') ~ 4.43 GeV

A "charged charmonium"!?
composed by $[c\bar{c}u\bar{d}]$
Very serious tetraquark candidate

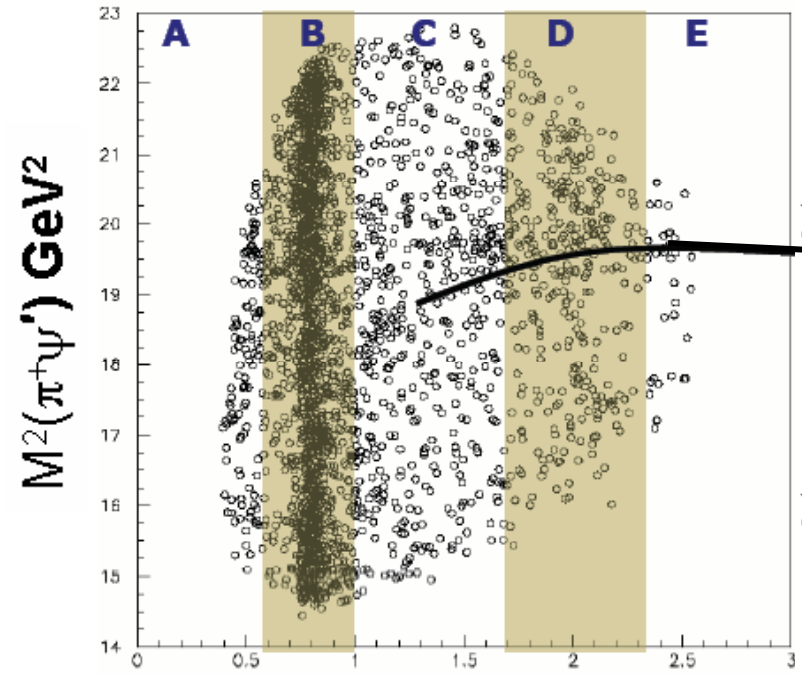
Belle's Dalitz Analysis

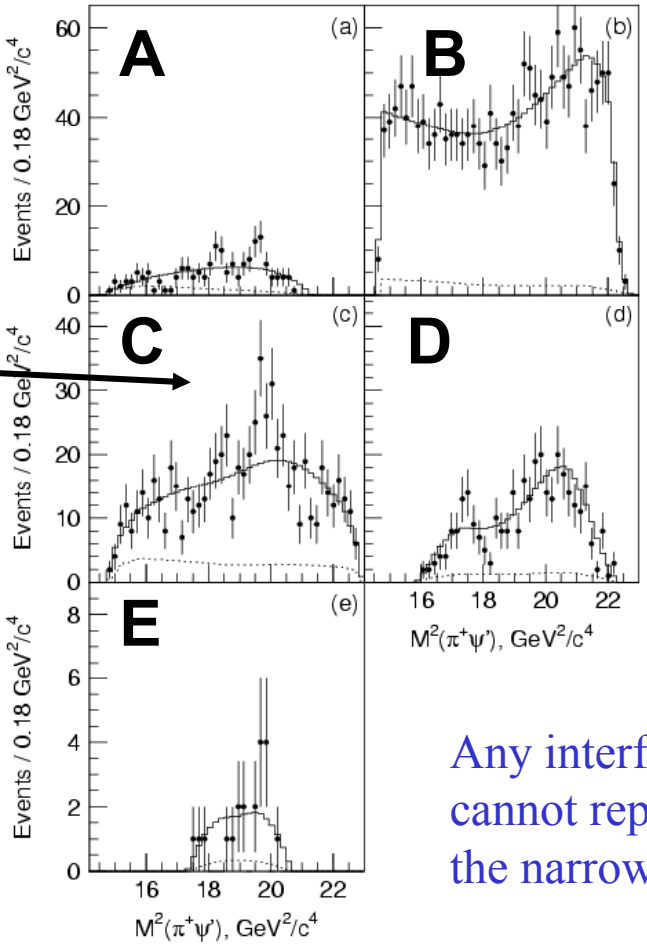
Full Dalitz-plane analysis
K*s included in the analysis:
κ, K*(892), K*(1410), $K^*_0(1430)$, $K^*_2(1430)$, K*(1680)

605 fb^{-1}

Preliminary
Presented at QWG6 (2008)

Fit without a Z resonance:
CL=0.1%



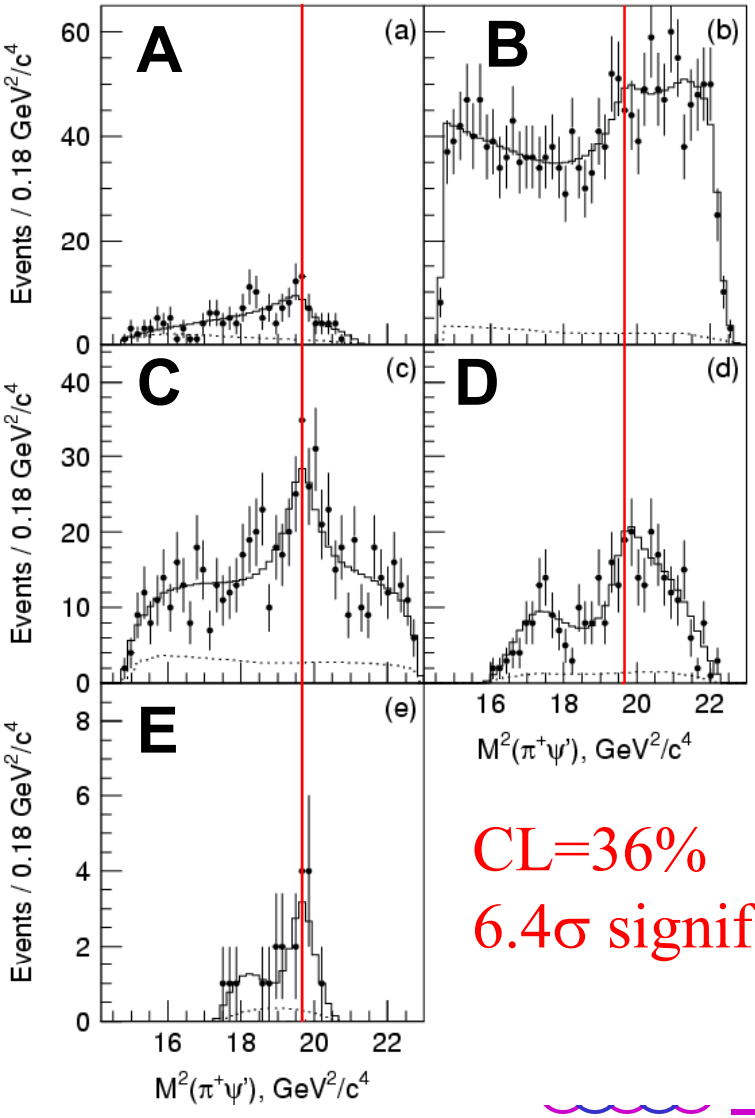


CL = 0.1%

Any interferences among K*'s cannot reproduce the narrow peak

Belle's Dalitz Analysis

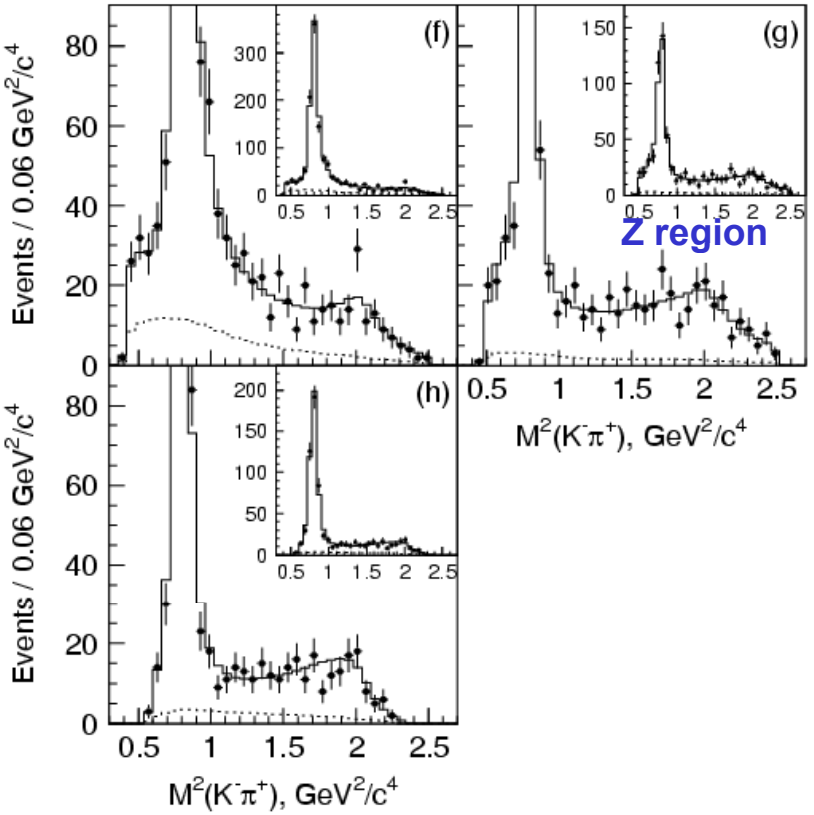
Fit with Z



CL=36%

6.4σ significance

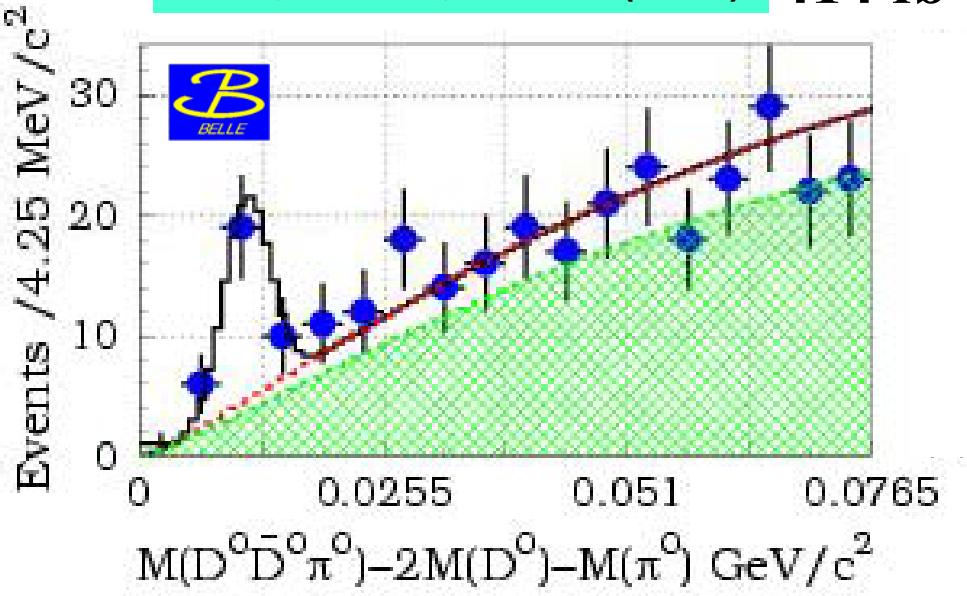
The fits in Kπ mass with Z



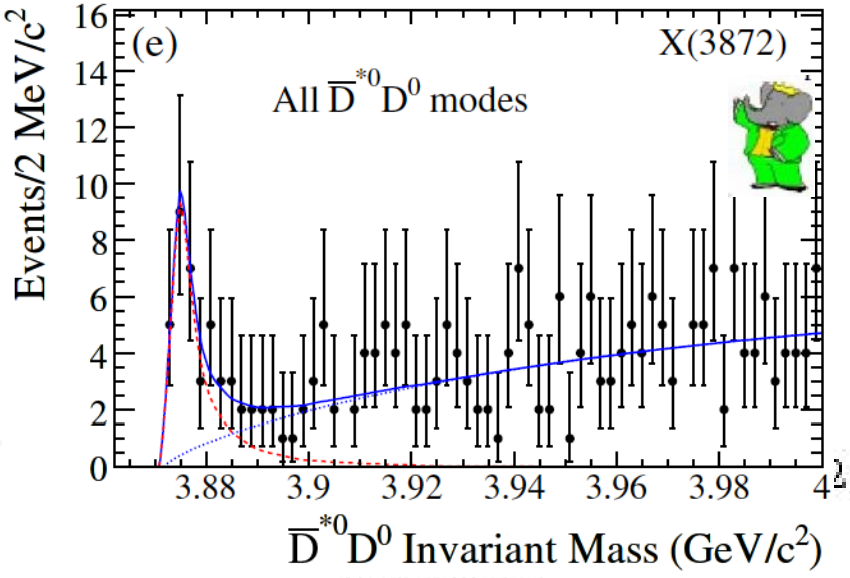
No characteristic features in view of Kπ spectrum

Observation of $D^0\bar{D}^0\pi^0$ threshold peak

Belle, PRL 97, 162002 (2006) **414 fb^{-1}**



BaBar, PRD 77, 011102 (2008)



$M = 3875.4 \pm 0.7^{+0.7}_{-1.7} \pm 0.8$ MeV/c^2

$3875.1^{+0.7}_{-0.5} \pm 0.5$ MeV

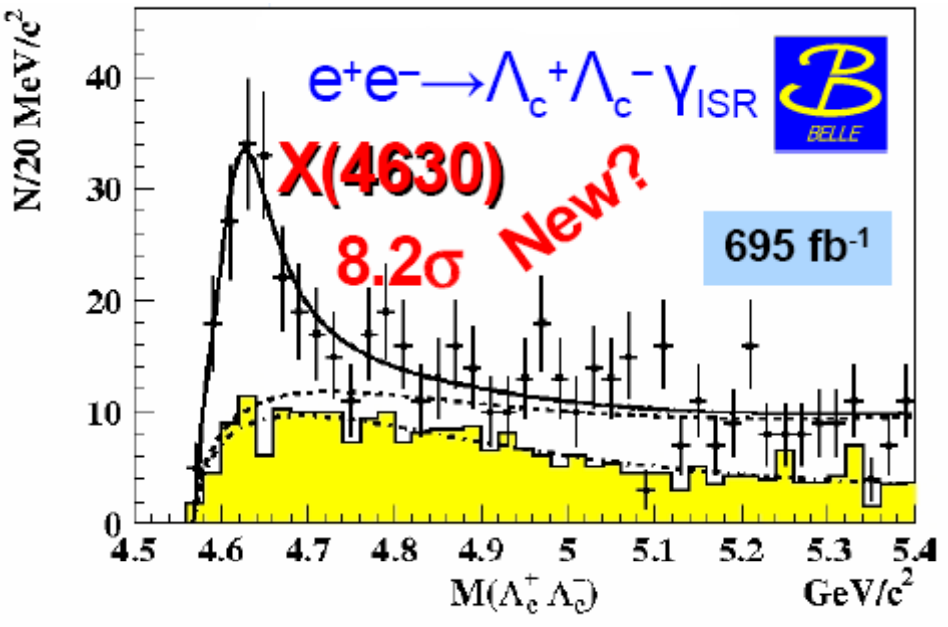
$$\frac{Br(X\to D^0\bar{D}^0\pi^0)}{Br(X\to \pi^+\pi^- J/\psi)} = 9 \pm 4$$

2^+ is less favorable
(D-wave needed somewhere in *PPP*)
$J^{PC} = 1^{++}$ favored

A heavier mass by 3 – 4 MeV/c^2 than in $X\to J/\psi\,\pi^+\pi^-$ observed

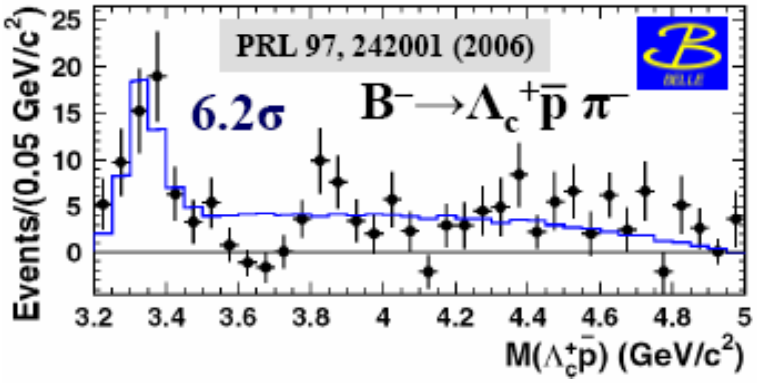
Study of $e^+e^- \to \gamma_{ISR} \Lambda_c \bar{\Lambda}_c$

PRL 101, 172001(2008)

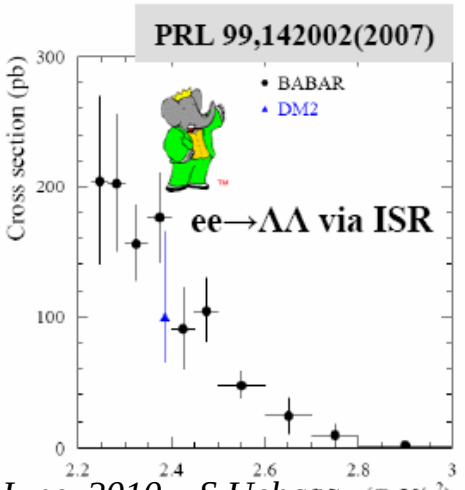


State	M, MeV/c^2	Γ_{tot}, MeV
X(4630)	4634^{+8+5}_{-7-8}	92^{+40+10}_{-24-21}
Y(4660)	$4664 \pm 11 \pm 5$	$48 \pm 15 \pm 3$

A popular nature of Baryon-antibaryon near-threshold structures



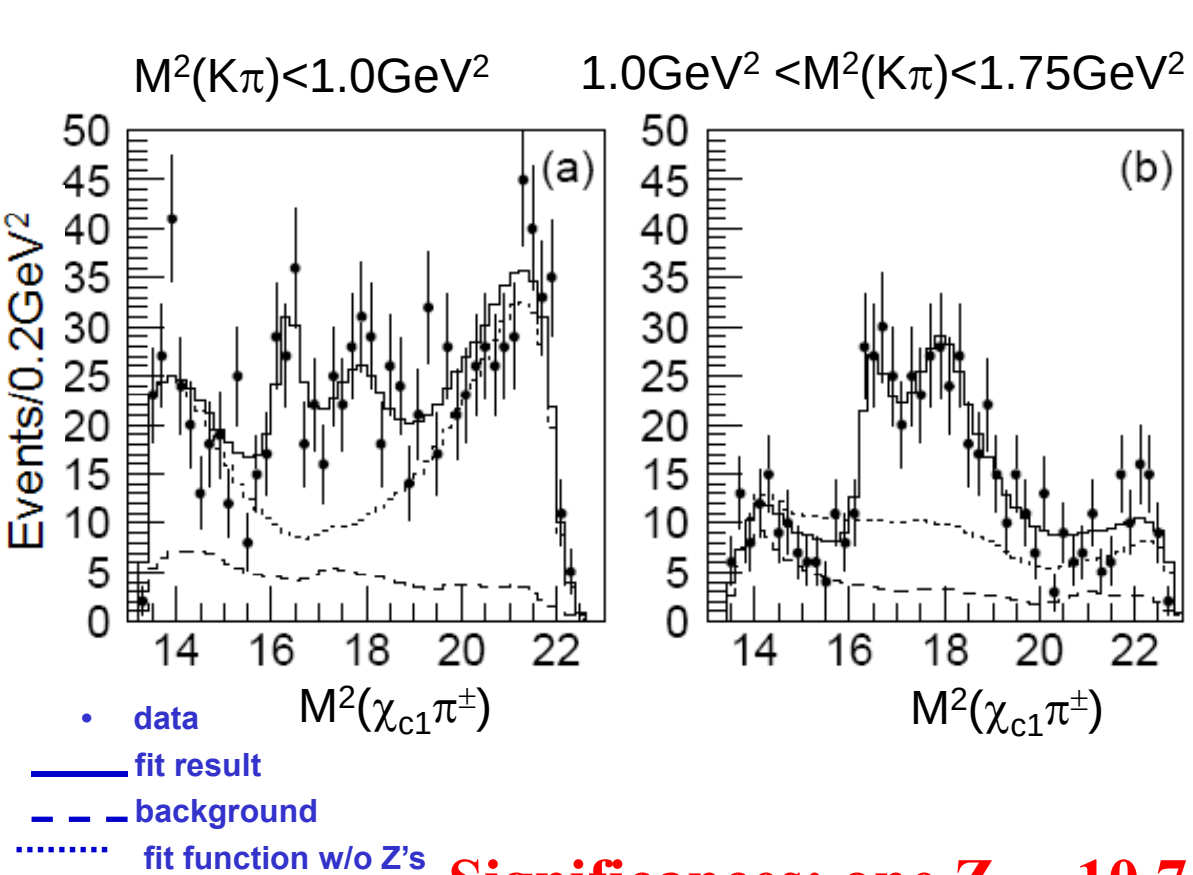
No peak for $\Lambda\bar{\Lambda}$



Additional two $\pi^+\chi_{c1}$ resonances (Z_1^+ & Z_2^+)

Belle, PRD 78, 072004 (2008)

Fit model: all known K* resonances + two ($\chi_{c1}\pi$) resonances



605 fb^{-1}

$$M_1 = (4051 \pm 14^{+20}_{-41})\ \mathrm{MeV}/c^2,$$
$$\Gamma_1 = (82^{+21+47}_{-17-22})\ \mathrm{MeV},$$
$$M_2 = (4248^{+44+180}_{-29-35})\ \mathrm{MeV}/c^2,$$
$$\Gamma_2 = (177^{+54+316}_{-39-61})\ \mathrm{MeV},$$

$BF(B^0 \to ZK^-)BF(Z \to \pi^+\chi_{c1})$:

$BFBF(Z_1) = (3.1^{+1.5+3.7}_{-0.9\ -0.17})\times 10^{-5}$

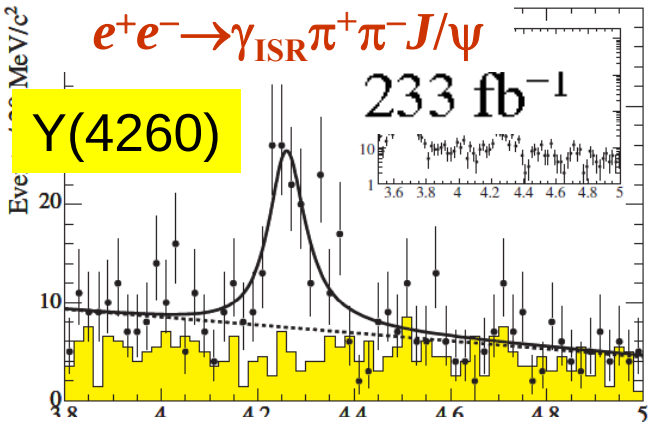
$BFBF(Z_2) = (4.0^{+2.3+19.7}_{-0.9\ -0.5})\times 10^{-5}$

Significances: one Z – 10.7 σ

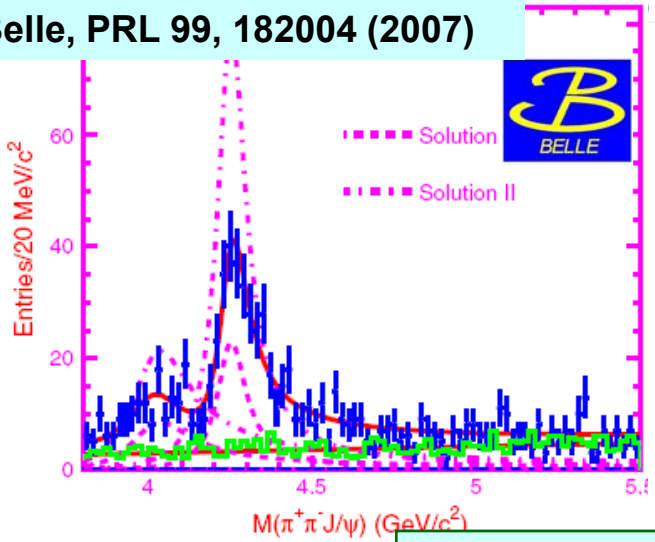
two Z's over one -- 5.7 σ

$e^+e^- \to \gamma_{ISR} Y(4260)$

BaBar, PRL95, 142001, (2005)



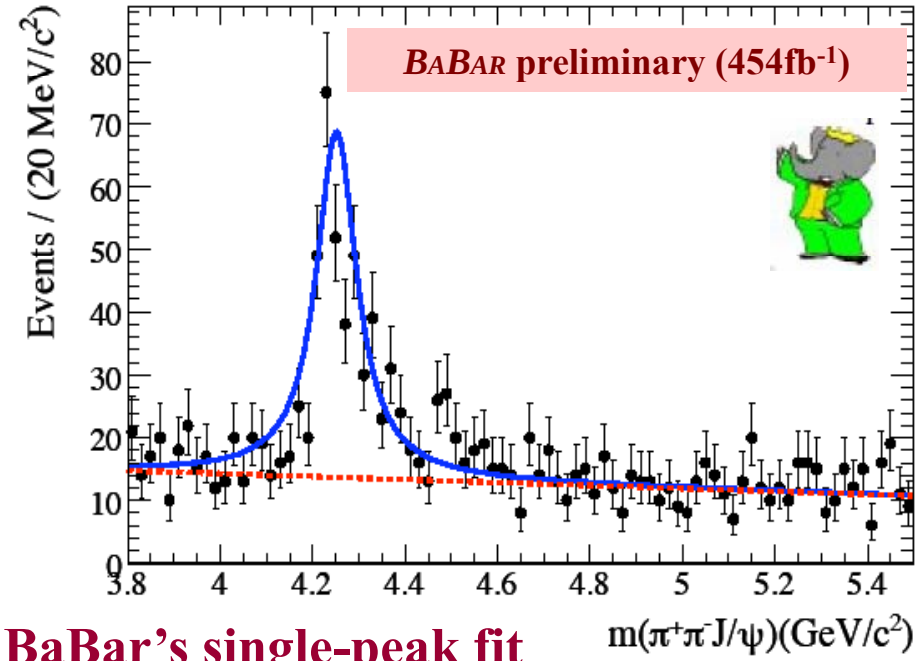
Belle, PRL 99, 182004 (2007)



Belle's Two-peak fit

M=4008 ±40 $^{+114}_{-28}$ MeV
Γ=226 ± 44 ± 87 MeV
M=4247 ± 12 $^{+17}_{-32}$ MeV
Γ=108 ± 19 ± 10 MeV

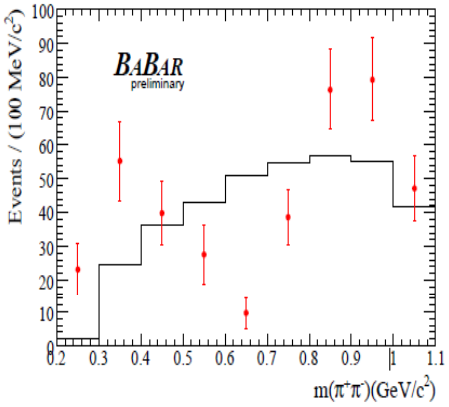
BaBar, arXiv:0808.1543(2008)



BaBar's single-peak fit

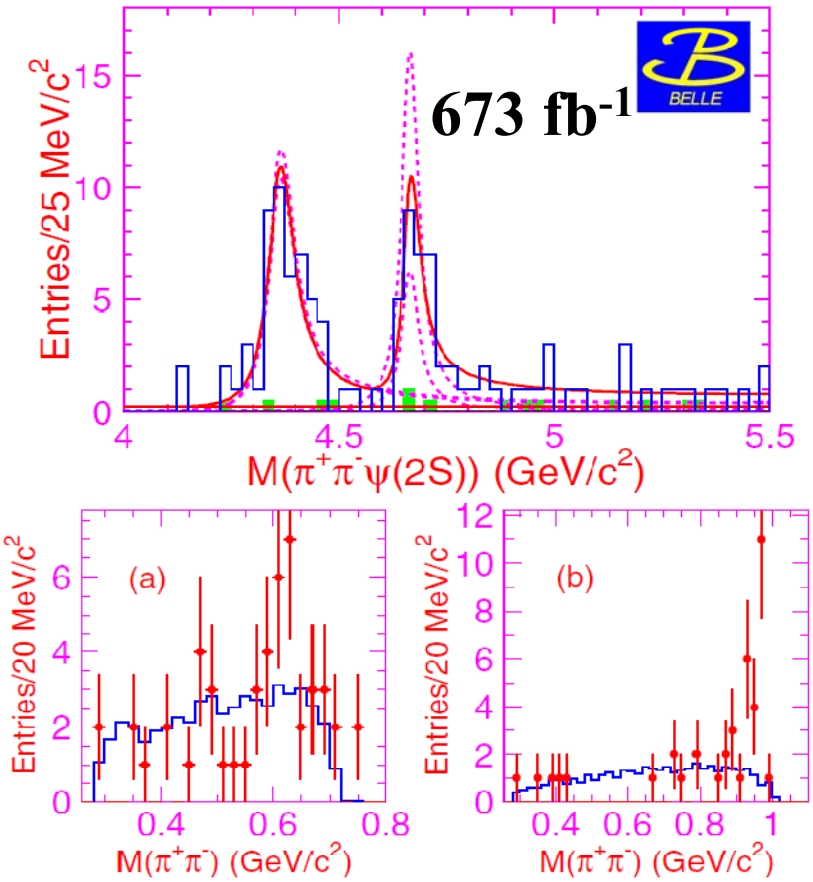
M=4252 ± 6 $^{+2}_{-3}$ MeV
Γ=105 ± 18 $^{+4}_{-6}$MeV

Y(4008) is not evident.

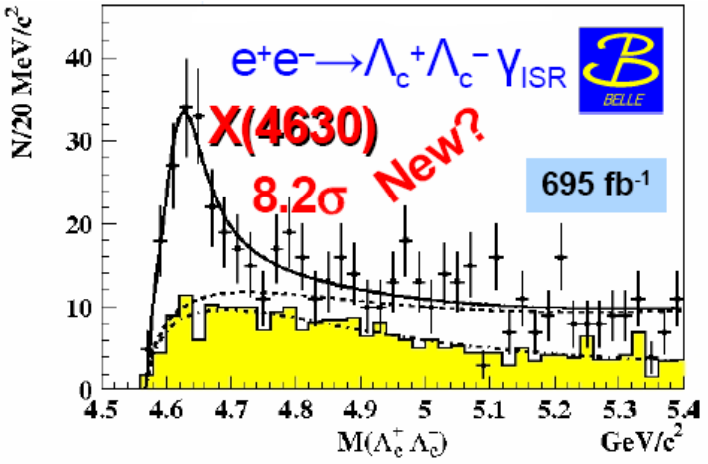


Y(4320) and Y(4664), and X(4630) in $\Lambda_c^+\Lambda_c^-$

Belle, PRL 99, 142002 (2007)



Belle. PRL 101, 172001(2008)



State	M, MeV/c^2	Γ_{tot}, MeV
X(4630)	4634^{+8+5}_{-7-8}	92^{+40+10}_{-24-21}
Y(4660)	$4664 \pm 11 \pm 5$	$48 \pm 15 \pm 3$

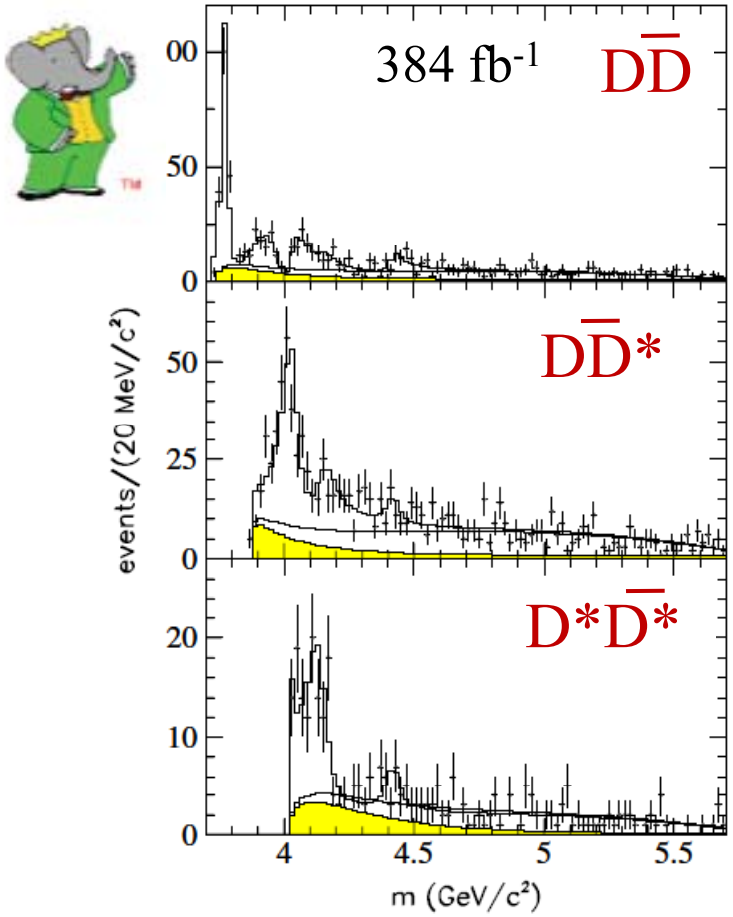
M= 4361 ± 9 ± 9 MeV
Γ= 74 ± 15 ±10 MeV

M= 4664 ± 11 ± 5 MeV
Γ= 48 ± 15 ±3 MeV

Or, a popular nature of Baryon-antibaryon near-threshold structures

ISR – $D^{(*)}\overline{D}^{(*)}$: from ψ states, and Y states?

BaBar, PRD 79 092001 (2009)



- **Full reconstruction of hadronic part**
- **Both charged and neutral final states**
- **Fit by sum of ψ states with**
  fixed masses&widths from PDG (due to limited statistics)

BF ratioes among $\psi \to D^{(*)}\overline{D}^{(*)}$

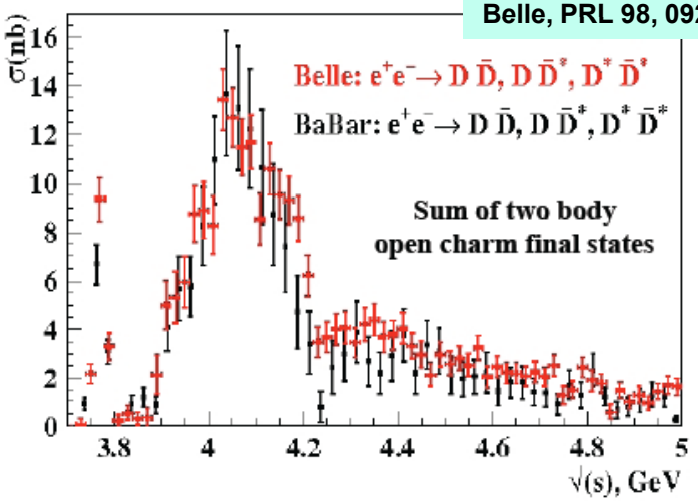
Ratio	Measurement
1) $\mathcal{B}(\psi(4040) \to D\bar{D})/\mathcal{B}(\psi(4040) \to D^*\bar{D})$	$0.24 \pm 0.05 \pm 0.12$
2) $\mathcal{B}(\psi(4040) \to D^*\bar{D}^*)/\mathcal{B}(\psi(4040) \to D^*\bar{D})$	$0.18 \pm 0.14 \pm 0.03$
3) $\mathcal{B}(\psi(4160) \to D\bar{D})/\mathcal{B}(\psi(4160) \to D^*\bar{D}^*)$	$0.02 \pm 0.03 \pm 0.02$
4) $\mathcal{B}(\psi(4160) \to D^*\bar{D})/\mathcal{B}(\psi(4160) \to D^*\bar{D}^*)$	$0.34 \pm 0.14 \pm 0.05$
5) $\mathcal{B}(\psi(4400) \to D\bar{D})/\mathcal{B}(\psi(4400) \to D^*\bar{D}^*)$	$0.14 \pm 0.12 \pm 0.03$
6) $\mathcal{B}(\psi(4400) \to D^*\bar{D})/\mathcal{B}(\psi(4400) \to D^*\bar{D}^*)$	$0.17 \pm 0.25 \pm 0.03$

No evidence is found for Y(4260)→ DD, DD*,D*D*

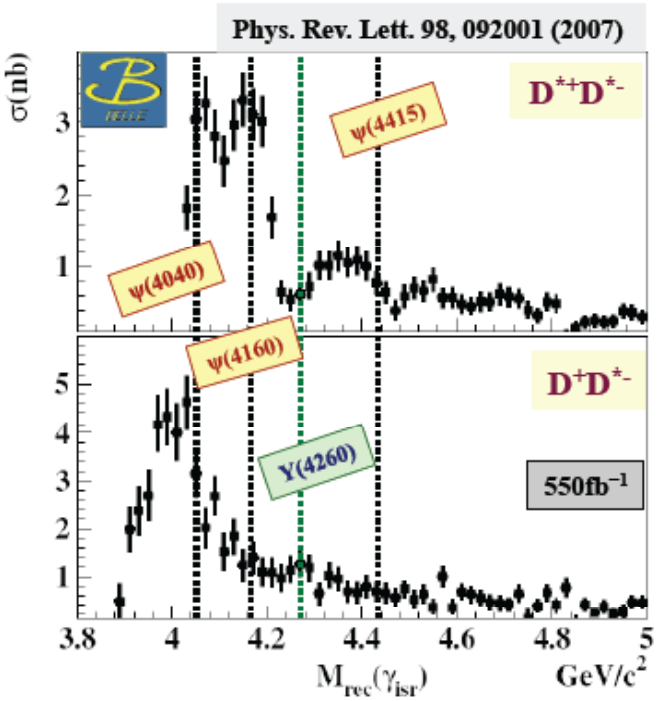
$$\frac{\mathcal{B}(Y(4260) \to D^*\bar{D})}{\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-)} < 34$$

$$\frac{\mathcal{B}(Y(4260) \to D^*\bar{D}^*)}{\mathcal{B}(Y(4260) \to J/\psi\pi^+\pi^-)} < 40$$

Belle, PRL 98, 092001 (2007)



ISR – $D^*\overline{D^{(*)}}(\pi)$ measurements from Belle

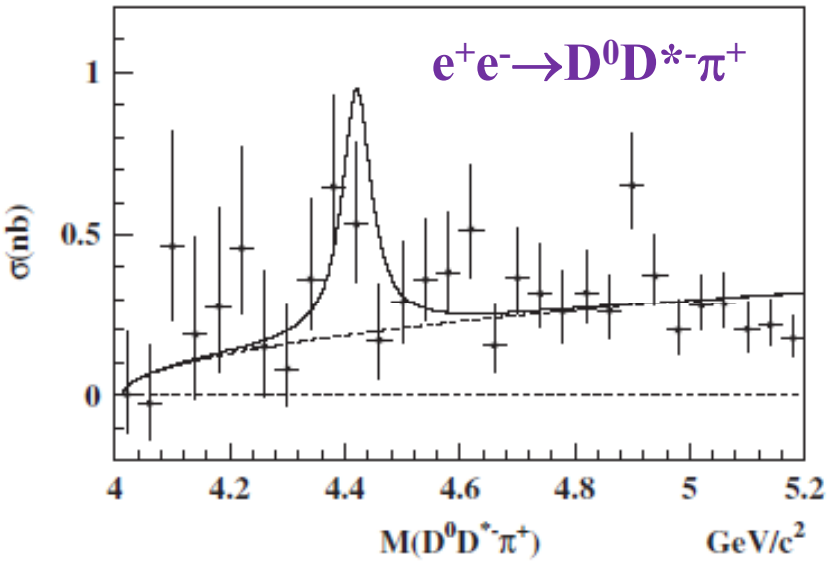


Systematic errors ≈ statistical errors

- D^+D^-
  - complicated shape of cross section
  - clear dip at $M(D^+D^-) \sim 4260$ GeV (similar to inclusive R)
- DD^*
  - broad peak at threshold (shifted relative to 4040 GeV)

Belle, PRD 80, 091101 (R)(2009)

695 fb^{-1}

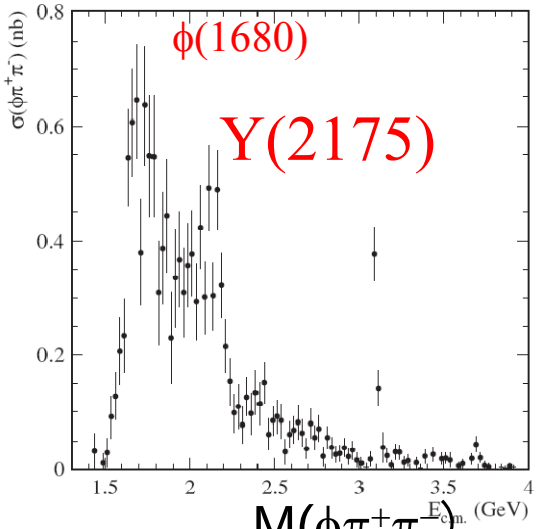


$$\mathcal{B}(Y(4260) \to D^0 D^{*-}\pi^+)/\mathcal{B}(Y(4260) \to \pi^+\pi^- J/\psi)$$

<9 (@90%CL)

No evidence of open-charm decay of these Y particles found so far.

$s\bar{s}$ sector; $e^+e^- \to Y(2175) \to \phi\pi^+\pi^-$



$M(\phi\pi^+\pi^-)$

PRD76,012008(2007)

BaBar: A clear structure above φ(1680), Identified as Y(2175).

$m_x = 2.175 \pm 0.010 \pm 0.015\ \mathrm{GeV}/c^2$

$\Gamma_x = 0.058 \pm 0.016 \pm 0.020\ \mathrm{GeV}/c^2$

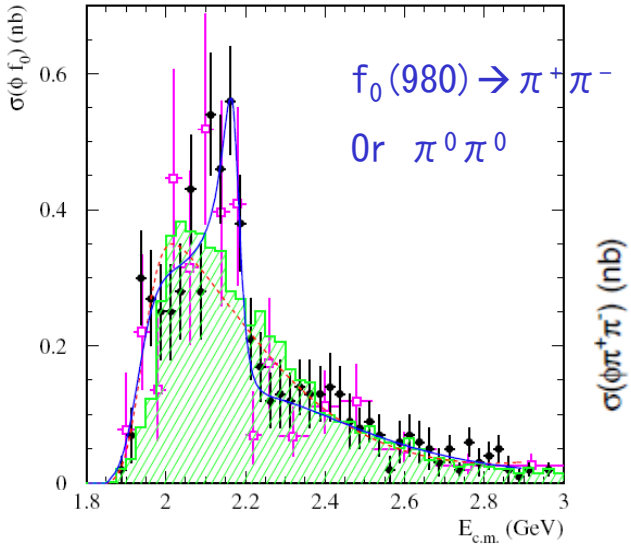
BESII confirms

Mass = 2.186 ± 0.010 ± 0.006 GeV/c²
Width = 0.065 ± 0.023 ± 0.017 GeV/c²

BELLE

$M(Y(2175)) = 2079 \pm 13\ ^{+79}_{-28}$ MeV/c²
$\Gamma(Y(2175)) = 192 \pm 23\ ^{+25}_{-61}$ MeV/c²

PRD 80, 031101(R) (2009)



$M(\phi f_0(980))$