Hadron spectroscopy at Belle

Jolanta Brodzicka (Krakow)

Hadron Workshop, Nagoya

6-7 December 2008

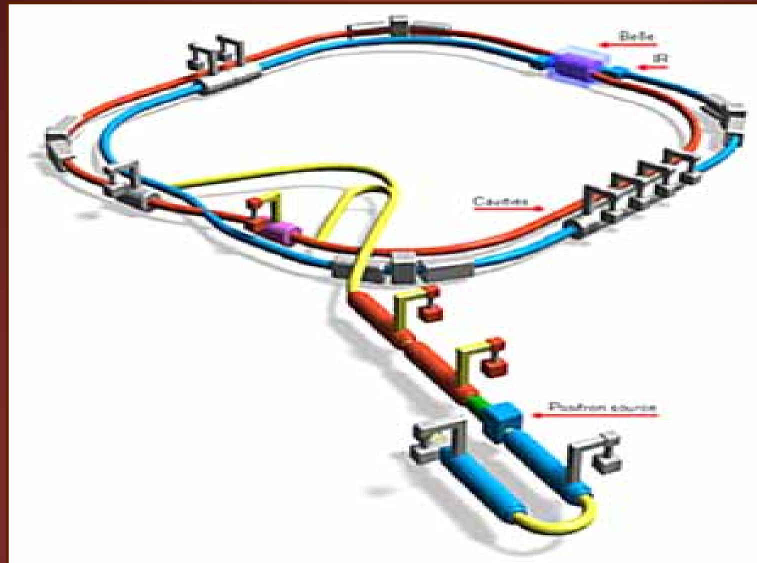
Belle at KEKB

- **KEKB: asymmetric e^+e^- collider**

  e^+: 3.5 GeV $\times$ e^-: 8.0 GeV

  $\sqrt{s}$=10.58 GeV = Υ(4S) mass

  $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$



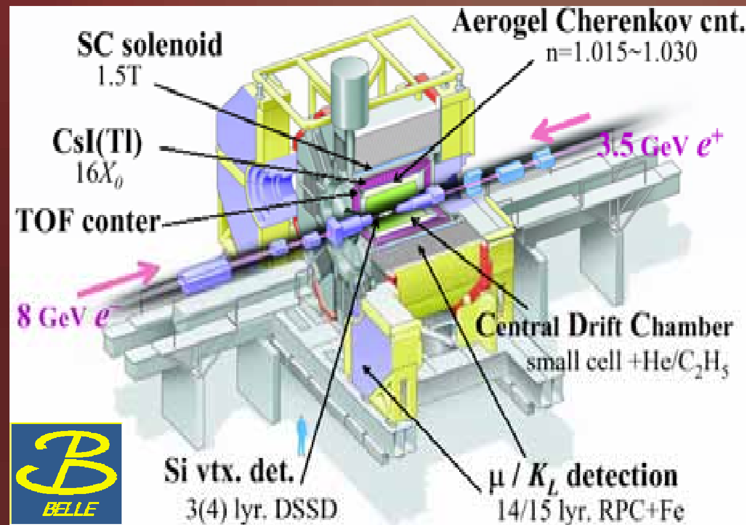
- **Operating since 1999**
- **Peak luminosity: $1.71\times10^{34}cm^{-2}s^{-1}$**
- **Integrated luminosity: 860 fb^{-1}**

  750 fb^{-1} @ Υ(4S)

  → ~ 780 * 10^6 $B\bar{B}$

  ~ 960 * 10^6 $c\bar{c}$

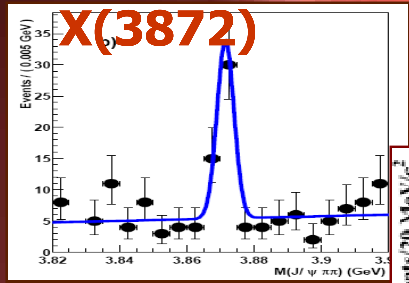
  Beauty and Charm Factory

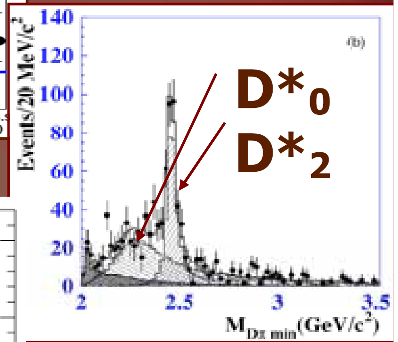


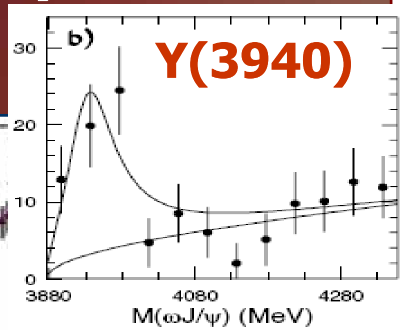
History of spectroscopy at Belle

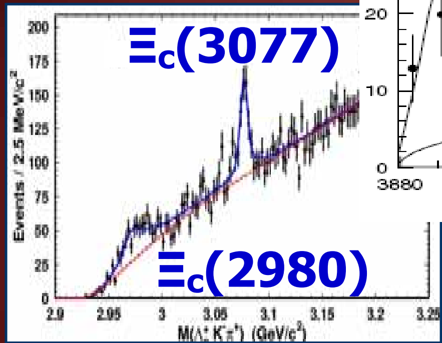
2002: $\eta_c' \to K_S K \pi$
- $X(3872) \to J/\psi \pi^+ \pi^-$
- $D^*_0(2308) \to D\pi$ and $D_1'(2420) \to D^*\pi$
- properties of $D^*_{s0}(2317)$ and $D_{s1}(2460)$
- $Y(3940) \to J/\psi \omega$
- $Z(3930) = \chi_{c2}' \to D\underline{D}$
- $X(3940) \to DD^*$
- $\Xi_c(2980)$ $\Xi_c(3077) \to \Lambda_c K \pi$
- Y family $\to \psi(1S,2S)\pi^+\pi^-$
- $D_{sJ}^+(2700) \to D^0 K^+$
- $X(4260) \to DD^*$
- $Z^+(4430) \to \psi(2S)\pi^+$
- $Z^+(4051)$ $Z^+(4281) \to \chi_{c1}\pi^+$

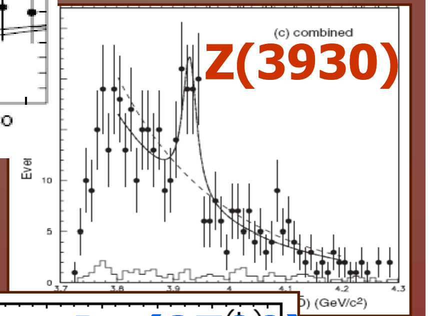
2008: $Y_b(?) \to \Upsilon \pi^+ \pi^-$

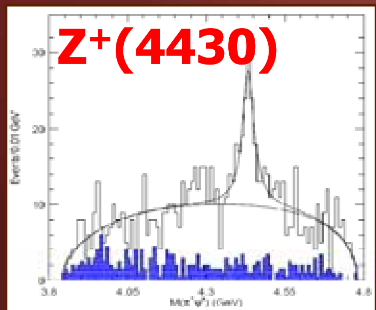


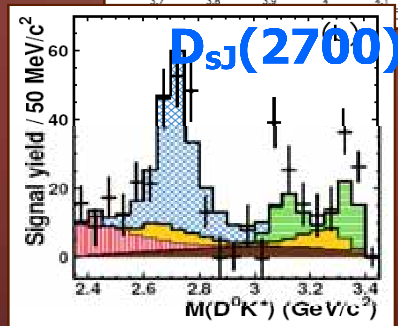






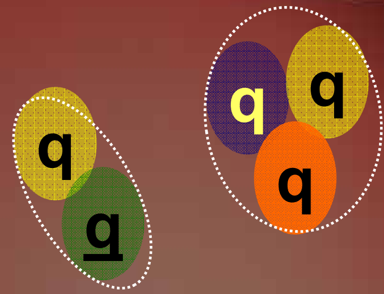






$c\underline{c}$-like XYZ states : exotics? I will focuse on them

Conventional vs exotic states

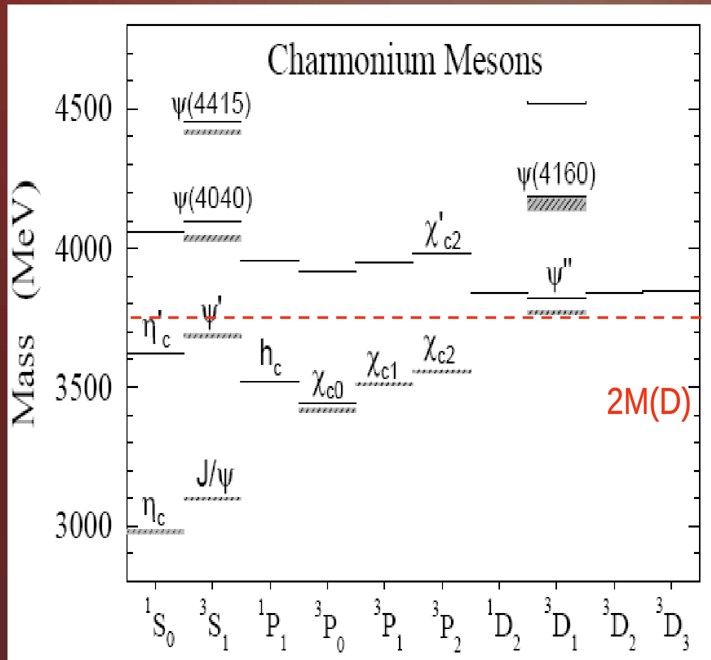


- Quark Model by Gell-Manna and Zweiga (1964):
  (qq) mesons and (qqq) baryons
  = conventional states

- QCD based potential models → hadron masses, decays,...
  Observed cc multiplets agree with the models' predictions

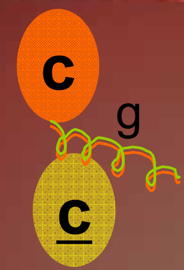
- States more complex than qq or qqq
  =exotics also predicted by the models

- cc spectrum „cleaner" than uu/dd/ss
  → cc-like exotics easier to identify

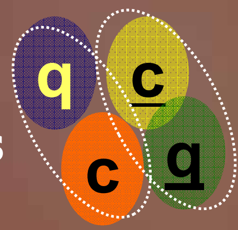


Menu of $c\bar{c}$-like exotics

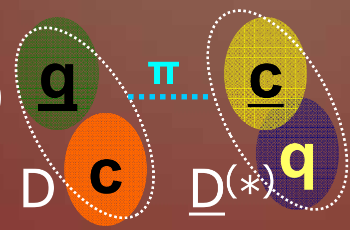
- **Hybrids**: $c\bar{c}$ + excited gluon (excited flux-tube)
  - Lattice QCD: lightest hybrids @ 4.2GeV
  - Exotic quantum numbers $J^{PC} = 0^{+-}, 1^{-+}, 2^{+-}$...
  - $\Gamma(H \to D\bar{D}^{**}) > \Gamma(H \to D\bar{D}^{(*)})$
  - Large $\Gamma(H \to \psi\pi\pi, \psi\omega, \ldots)$



- **Tetraquarks**: diquark-antidiquark $[cq][\bar{c}\bar{q}]$
  - Tightly bound diquarks (gluon exchange)
  - Decay: „coloured" quarks rearrange into „white" mesons
    → dissociation



- **Molecules**: $M(c\bar{q})M(\bar{c}q)$
  - Meson and antimeson loosely bound (pion exchange)
  - Decay: dissociation into constituent mesons



How to identify exotic $c\bar{c}$ hadron?

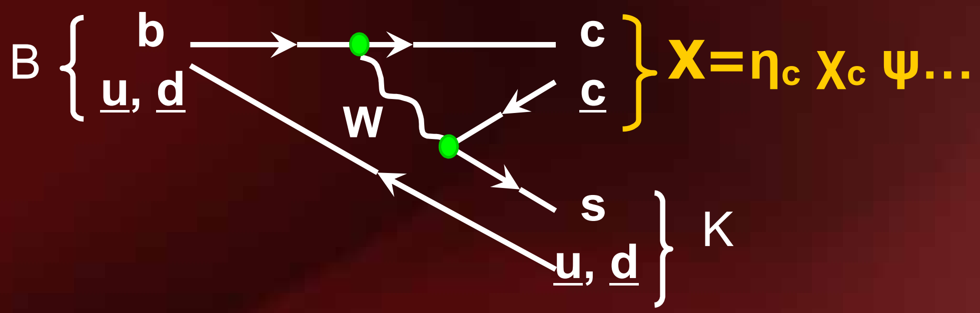
- J^{PC} forbidden for conventional $c\bar{c}$
- Final states with non-zero electric charge and/or strangeness:
  $J/\psi\pi^- = (c\bar{c})(\bar{u}d)$ $D_s^+D^- = (c\bar{s})(\bar{c}d)$
- Too small/large rates in some decay modes

Recently observed $c\bar{c}$-like states

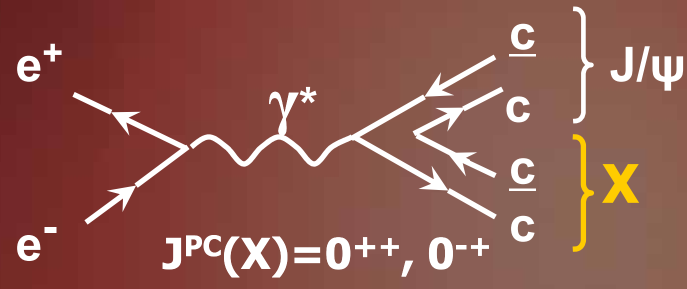
State	EXP	M + i Γ (MeV)	J^{PC}	Decay Modes Observed	Production Modes Observed
X(3872)	Belle,CDF, D0, Cleo, BaBar	$3871.2\pm0.5 + i(<2.3)$	1^{++}	$\pi^+\pi^- J/\psi$, $\pi^+\pi^-\pi^0 J/\psi$, $\gamma J/\psi$	B decays, ppbar
	Belle BaBar	$3875.4\pm0.7^{+1.2}_{-2.0}$ $3875.6\pm0.7^{+1.4}_{-1.5}$		$D^0\bar{D}^0\pi^0$	B decays
Z(3930)	Belle	$3929\pm5\pm2 + i(29\pm10\pm2)$	2^{++}	$D^0\bar{D}^0$, D^+D^-	$\gamma\gamma$
Y(3940)	Belle BaBar	$3943\pm11\pm13 + i(87\pm22\pm26)$ $3914.3^{+3.8}_{-3.4}\pm1.6 + i(33^{+12}_{-8}\pm0.60)$	J^{++}	$\omega J/\psi$	B decays
X(3940)	Belle	$3942^{+7}_{-6}\pm6 + i(37^{+26}_{-15}\pm8)$	J^{P+}	DD^*	e^+e^- (recoil against J/ψ)
Y(4008)	Belle	$4008\pm40^{+72}_{-28} + i(226\pm44^{+87}_{-79})$	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^- (ISR)
X(4160)	Belle	$4156^{+25}_{-20}\pm15 + i(139^{+111}_{-61}\pm21)$	J^{P+}	D^*D^*	e^+e^- (recoil against J/ψ)
Y(4260)	BaBar Cleo Belle	$4259\pm8^{+3}_{-6} + i(88\pm23^{+6}_{-4})$ $4284^{+17}_{-16}\pm4 + i(73^{+39}_{-25}\pm5)$ $4247\pm12^{+17}_{-32} + i(108\pm19\pm10)$	1^{--}	$\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$, $K^+K^- J/\psi$	e^+e^- (ISR), e^+e^-
Y(4350)	BaBar Belle	$4324\pm24 + i(172\pm33)$ $4361\pm9\pm9 + i(74\pm15\pm10)$	1^{--}	$\pi^+\pi^-\psi(2S)$	e^+e^- (ISR)
$Z^+(4430)$	Belle	$4433\pm4\pm1 + i(44^{+17}_{-13}{}^{+30}_{-11})$	J^P	$\pi^+\psi(2S)$	B decays
Y(4620)	Belle	$4664\pm11\pm5 + i(48\pm15\pm3)$	1^{--}	$\pi^+\pi^-\psi(2S)$	e^+e^- (ISR)
$Z^+(4051)$	Belle	$4051\pm14^{+20}_{-41} + i(82^{+21}_{-17}{}^{+47}_{-22})$	J^P	$\pi^+\chi_{c1}$	B decays
$Z^+(4248)$	Belle	$4248^{+44}_{-29}{}^{+180}_{-135} + i(177^{+54}_{-39}{}^{+316}_{-61})$	J^P	$\pi^+\chi_{c1}$	B decays

Production of $c\bar{c}$ in B Factory

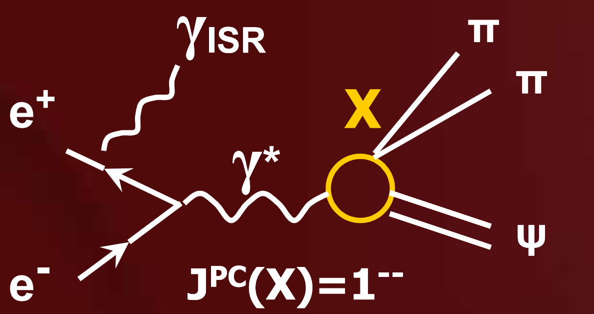
- **B meson decays:**
  $B \to X_{c\bar{c}} K$ (BF~10^{-3})



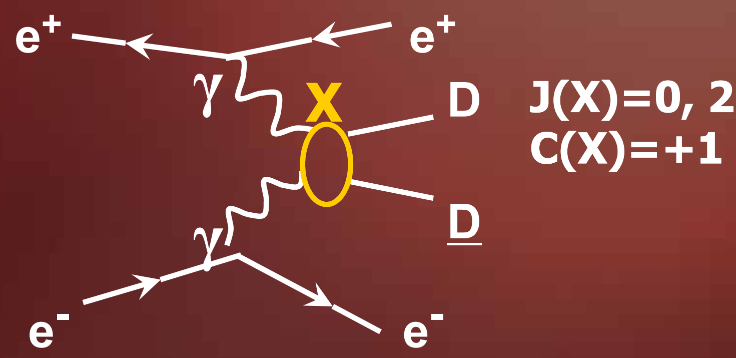
- **double $c\bar{c}$ production**
  $e^+e^- \to J/\psi X_{c\bar{c}}$



- **initial state radiation (ISR)**
  $e^+e^- \to \gamma_{ISR} X_{c\bar{c}} \to \gamma_{ISR}\ \psi\pi\pi$



- **$\gamma\gamma$ collision**
  $e^+e^- \to \gamma\gamma \to X_{c\bar{c}} \to D\bar{D}$

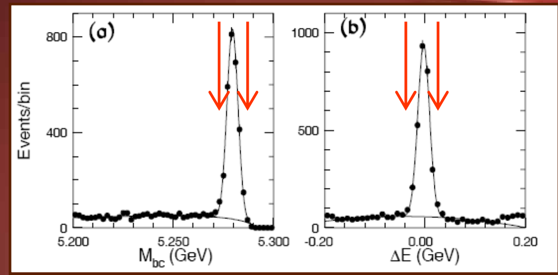


Good experimental environment to search for new resonances

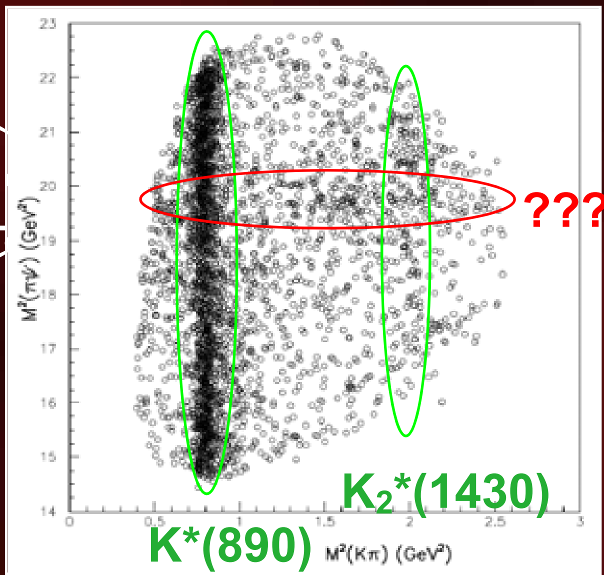
PRL100, 142001 (2008)

Observation of $Z^+(4430) \rightarrow \psi'\pi^+$

- **Study of $B \rightarrow \psi'\pi^+K$ using 657M $B\bar{B}$**
- **$\psi' \rightarrow e^+e^-, \mu^+\mu^-, J/\psi\pi^+\pi^-$**

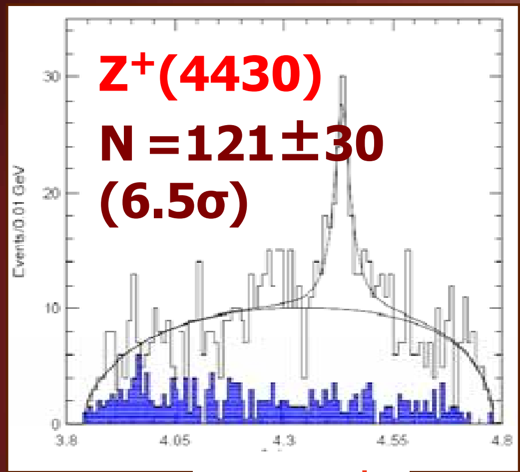


Mbc ΔE



M²(Kπ⁺)

after K* veto



M(ψ'π⁺)

$M = 4433 \pm 4 \pm 2$ MeV

$\Gamma = 45^{+18\ +30}_{-13\ -13}$ MeV

Too low statistic to determine J^P

First charged cc-like state! Must be exotic!

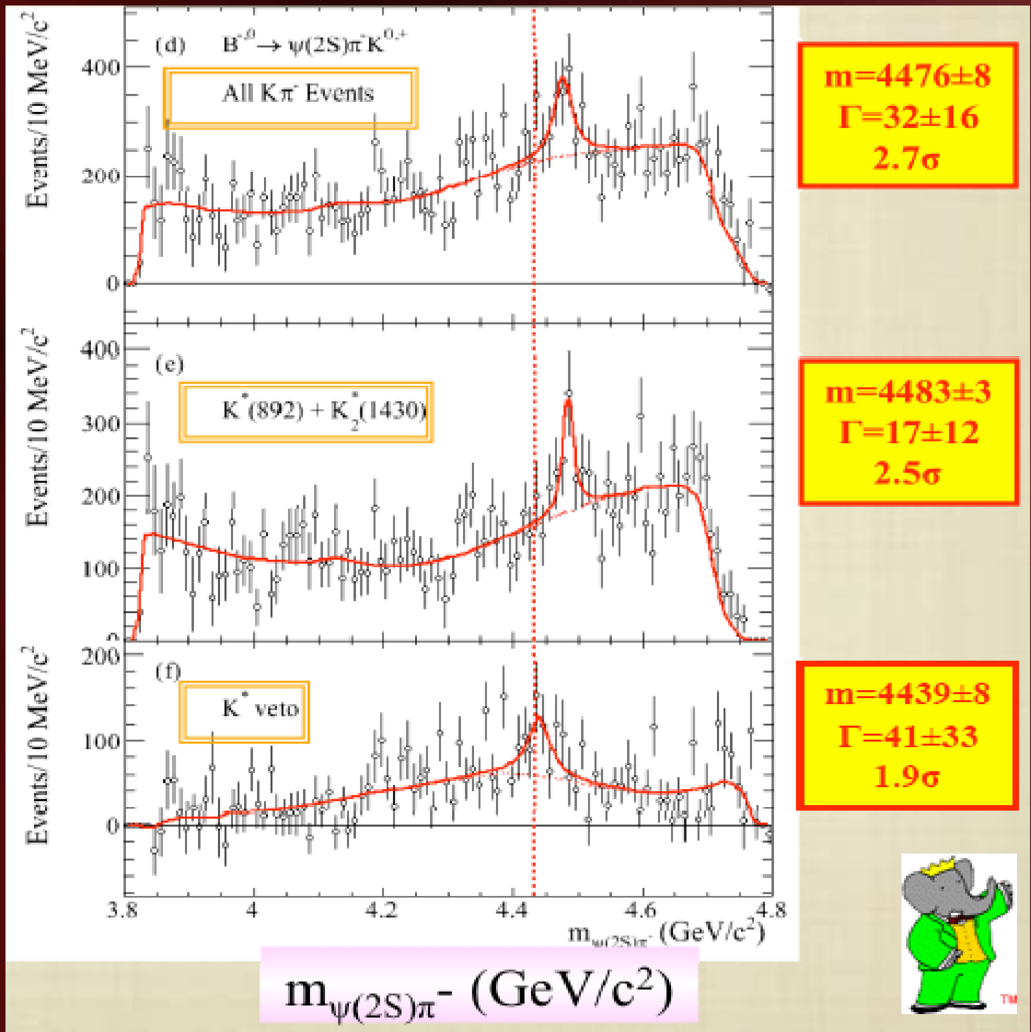
Proposed interpretations:

- **$[cu][\bar{c}\bar{d}]$ tetraquark; neutral partner in $\psi'\pi^0$ expected**
- **$D^*\bar{D}_1(2420)$ molecule; should decay to $D^*\bar{D}^*\pi$**

hep-ex/0811.0564

No significant $Z^+(4430)$ in Babar

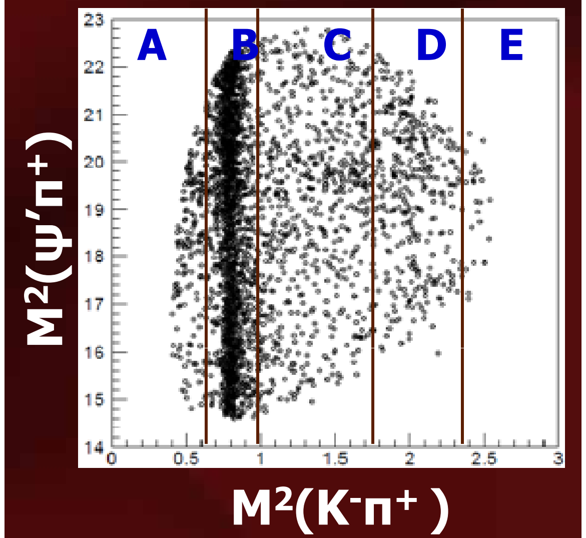
- $B \to \psi' \pi^+ K$ studied using 413/fb
- Mass spectra corrected for efficiency

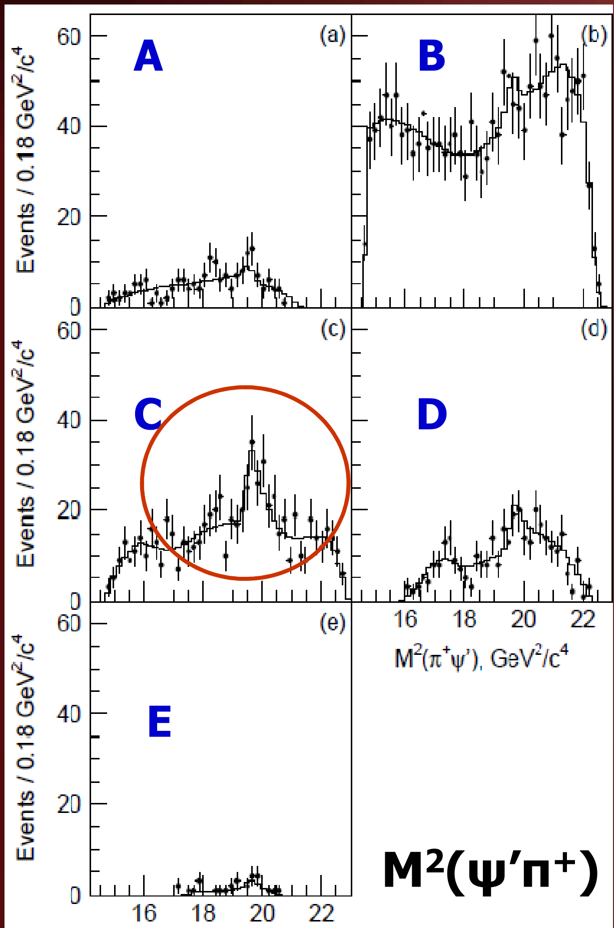


B→ψ′π⁺K Dalitz plot analysis

- B→ψ′π⁺K amplitude: coherent sum of Breit-Wigner contributions
- Maximum likelihood fit to Dalitz plot
- Models: all known K*→Kπ⁺ resonances only

  all known K*→Kπ⁺ resonances and Z→ψ′π⁺ ⬅ favored by data





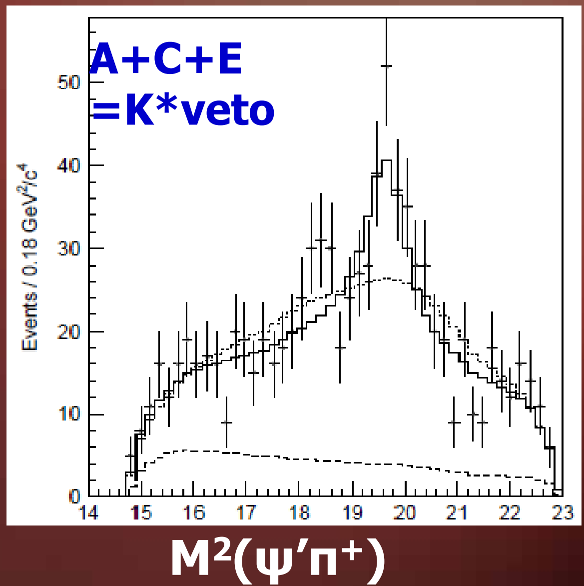
Significance: 6.4σ

Fit CL: 36%

Z⁺(4430) confirmed

$$M = (4443^{+15+17}_{-12-13})\ \mathrm{MeV}/c^2,$$

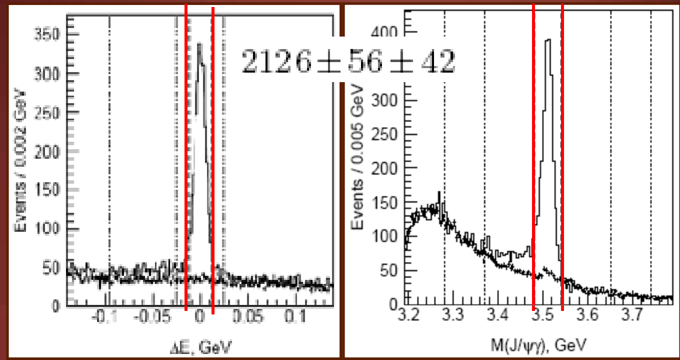
$$\Gamma = (109^{+86+57}_{-43-52})\ \mathrm{MeV},$$



$\underline{B}^0 \to \chi_{c1}\pi^+K^-$ study. More Z's

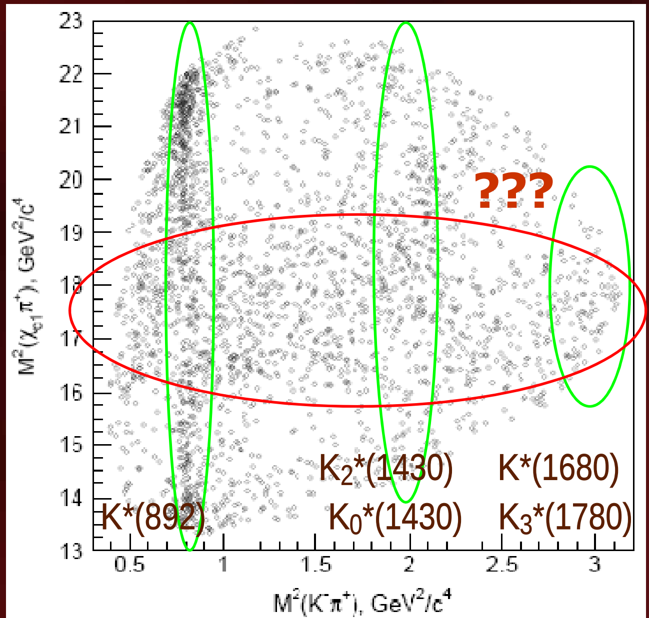
PRD 78, 072004 (2008)

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



ΔE　　M(J/ψγ)

$$\mathcal{B}(\overline{B}^0 \to K^-\pi^+\chi_{c1}) = (3.83 \pm 0.10 \pm 0.39) \times 10^{-4}$$



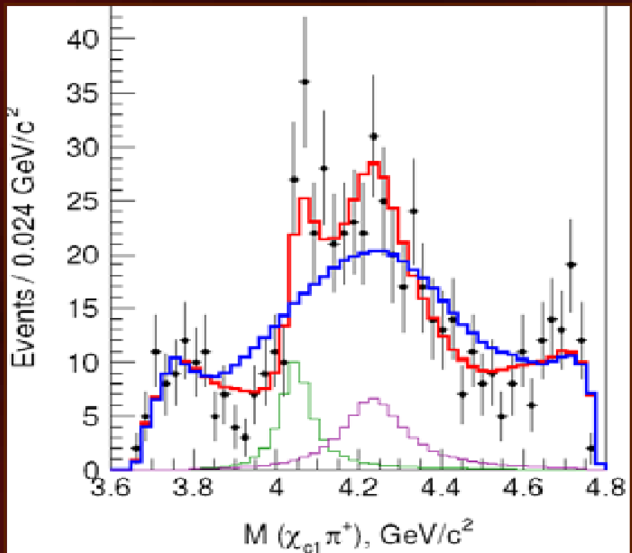
$M^2(\chi_{c1}\pi^+)$

$M^2(K^-\pi^+)$

- $\underline{B}^0 \to \chi_{c1}\pi^+K^-$ amplitude: coherent sum of Breit-Wigner contributions
- Maximum likelihood fit performed
- Models tried:
  - known K*'s→Kπ only
  - K*'s + one $Z \to \chi_{c1}\pi^+$
  - K*'s + two Z states : favored by data

$Z^+_{1,2} \to \chi_{c1}\pi^+$ exotic states

- **Model with two Z's significantly favored by data**
- **Spin of Z states not determined: spin 0 and 1 give similar fit qualities**



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

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

$$\mathcal{B}(\overline{B}^0 \to K^- Z_1^+) \times \mathcal{B}(Z_1^+ \to \pi^+\chi_{c1}) = (3.1^{+1.5+3.7}_{-0.9-1.7}) \times 10^{-5},$$
$$\mathcal{B}(\overline{B}^0 \to K^- Z_2^+) \times \mathcal{B}(Z_2^+ \to \pi^+\chi_{c1}) = (4.0^{+2.3+19.7}_{-0.9-\ \ 0.5}) \times 10^{-5}.$$

fit for null model

fit for double Z model

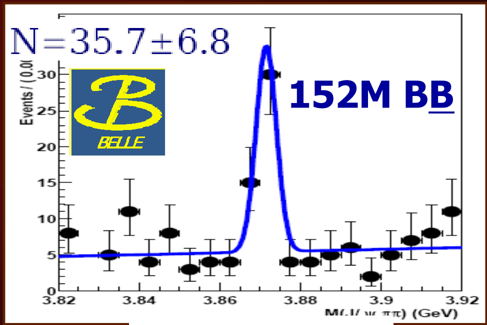
Z_1 contribution

Z_2 contribution

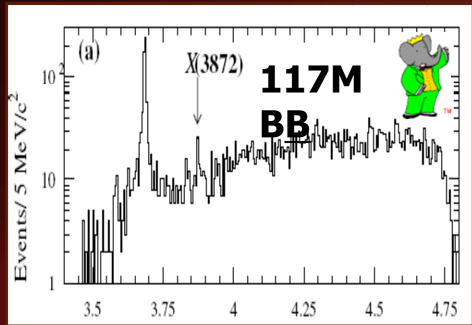
Non-zero charge suggests multiquark interpretation of Z_1 and Z_2

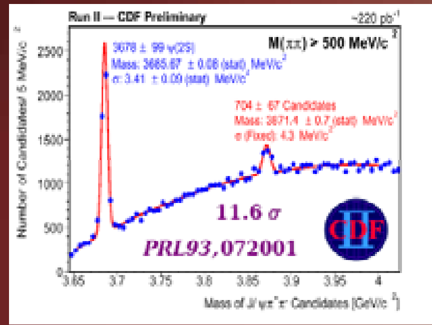
$c\bar{c}$-like example: X(3872)

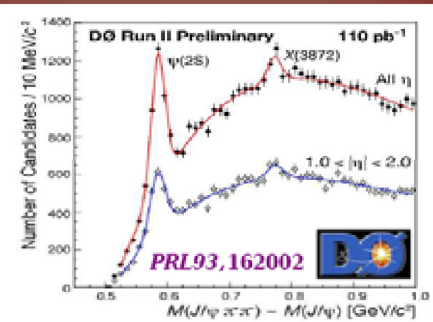
- $X(3872) \to J/\psi \pi^+ \pi^-$ observed in $B^+ \to X(3872) K^+$ by Belle PRL91, 262001 (2003)
- Confirmed by BaBar, CDF, D0



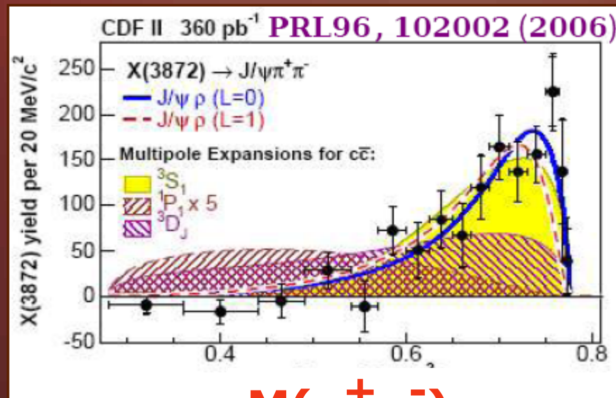
M(J/ψπ⁺π⁻)







- $m_X = 3871.2 \pm 0.5$ MeV $m_X - (m_{D^{*0}} + m_{D^0}) = -0.6 \pm 0.6$MeV $\Gamma < 2.3$MeV
- $M(\pi^+\pi^-)$ suggests $X(3872) \to J/\psi\, \rho$ (S- or P-wave)
- Other decay modes: $J/\psi\gamma$, $\psi(2S)\gamma$, $J/\psi\omega$, $D\bar{D}^*$, no $X \to D\bar{D}$
- $J^{PC} = 1^{++}, 2^{-+}$ favored (from angular analysis by CDF, $M(\pi^+\pi^-)$, decay modes)



M(π⁺π⁻)

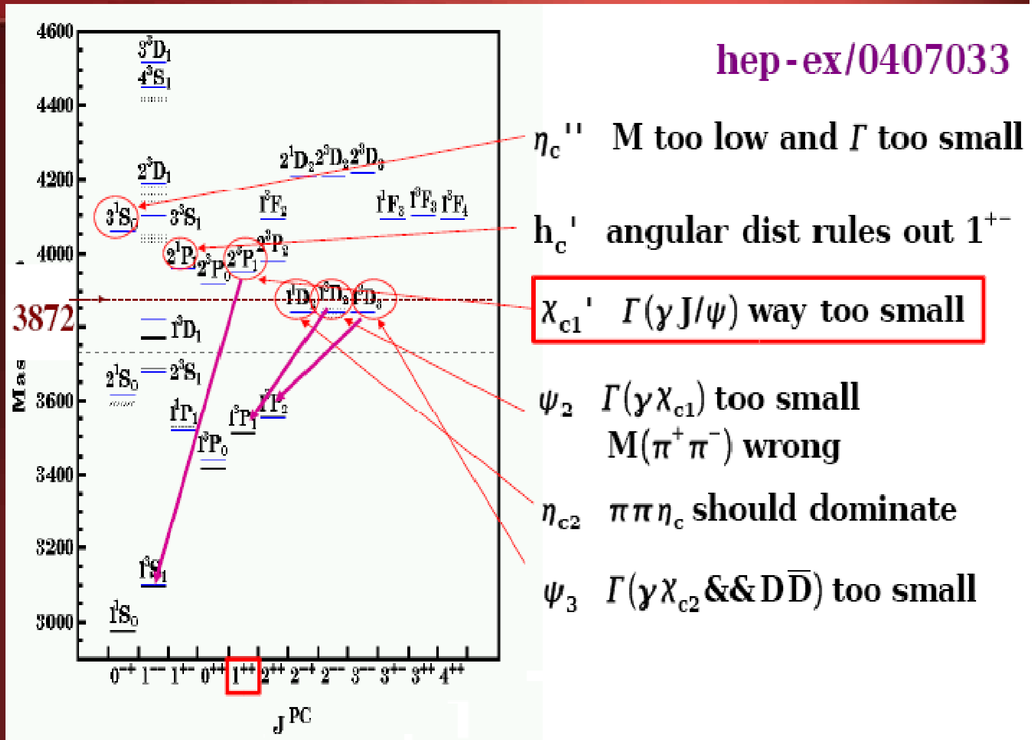
What is X(3872) ?

- $c\bar{c}$? No obvious assignment
- $D^0\bar{D}^{*0}$ molecule?
  Non-trivial line shape
  $\Gamma(X \to D\bar{D}^*) > \Gamma(X \to J/\psi\pi\pi)$
  Production in B^0 suppressed in regard to B^+

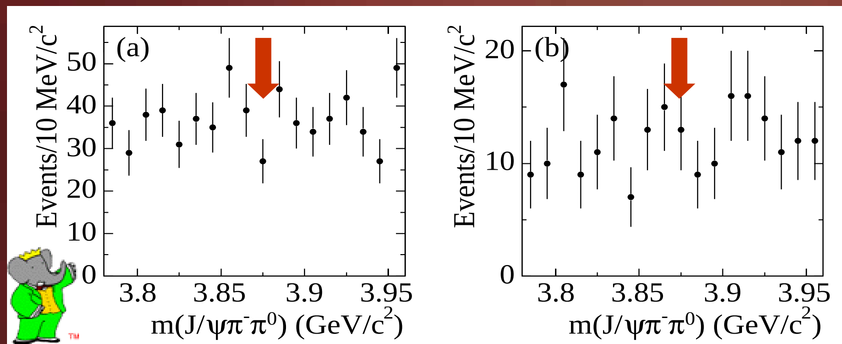
Braaten et al. hep-ph/0710.5482

- 4-quark?
  X_u [uc][$\overline{uc}$] X_d [dc][$\overline{dc}$]
  Different mass of X produced in B^0 and B^+
  Finding charged X is critical (no evidence so far)

Maiani, Polosa et al.
PRD 71, 014028 (2005)



PRD71, 031501 (2005)

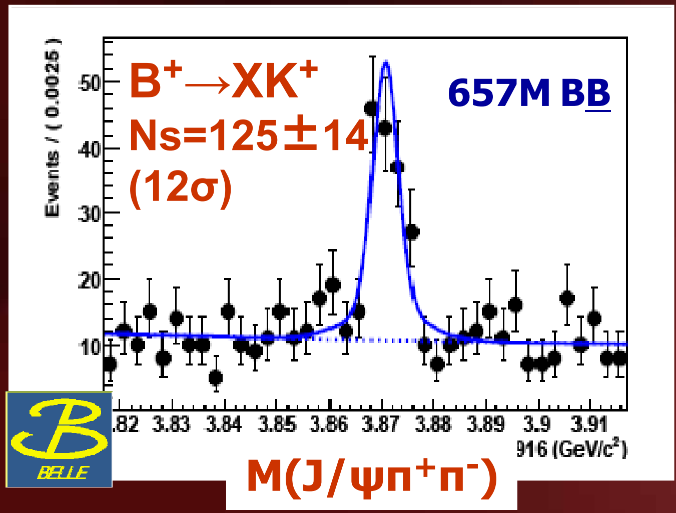


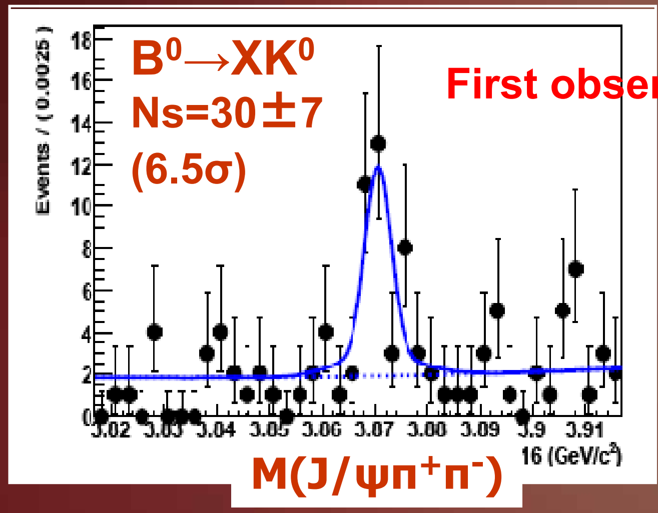
$M(J/\psi\pi^-\pi^0)$

hep-ex/0809.1224

X(3872) in B^+ vs B^0 decays

- **Study of $X(3872) \rightarrow J/\psi\pi^+\pi^-$ in $B^+ \rightarrow XK^+$ and $B^0 \rightarrow XK^0_s$**





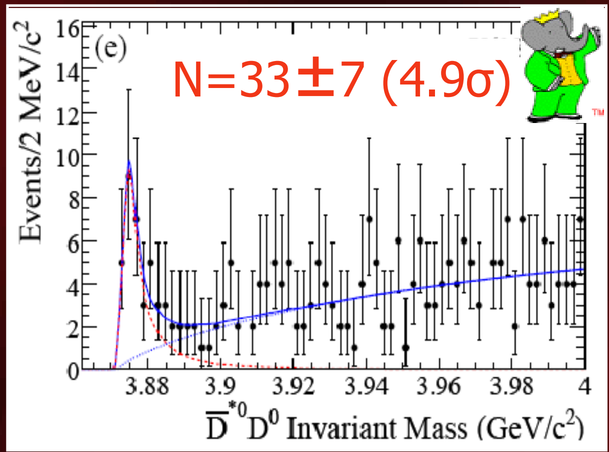
$$\delta M_X = M(X \text{ from } B^+) - M(X \text{ from } B^0) = 0.22 \pm 0.90 \pm 0.27 \text{ MeV}$$

$$R^{0/+} = \frac{\mathcal{B}(B^0 \to X(3872)K^0)}{\mathcal{B}(B^+ \to X(3872)K^+)} = 0.94 \pm 0.24 \pm 0.10$$

- **Similar properties of X(3872) from B^+ and B^0 decays**

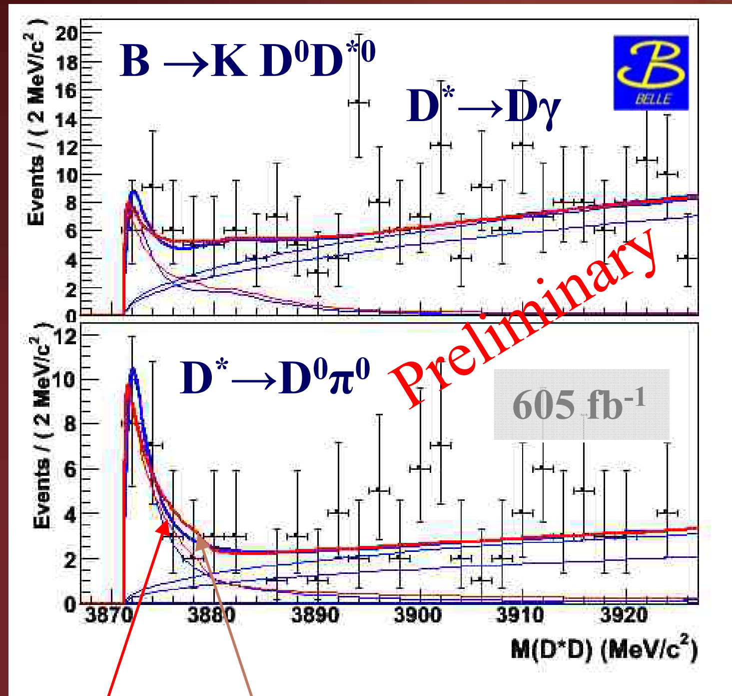
$X(3872) \to D^0\bar{D}^{*0}$ (?)

- $X(3872) \to \bar{D}^{*0}D^0$ in $B^+ \to \bar{D}^{*0}D^0K$



PRD77, 011102(2008)

$M(X)=3875.1^{+0.7}_{-0.5} \pm 0.5$MeV
$\Gamma=3.0^{+1.9}_{-1.4} \pm 0.9$ MeV



hep-ex/0810.0358

Flatte vs BW similar result: 8.8σ

$M(X)=3872.6^{+0.5}_{-0.4} \pm 0.4$MeV
$\Gamma=3.9^{+2.5}_{-1.3}{}^{+0.8}_{-0.3}$ MeV

- New Belle M(X) measurement ruled out scenario of two states: X(3872)→J/ψππ and X(3875)→$\bar{D}$*D

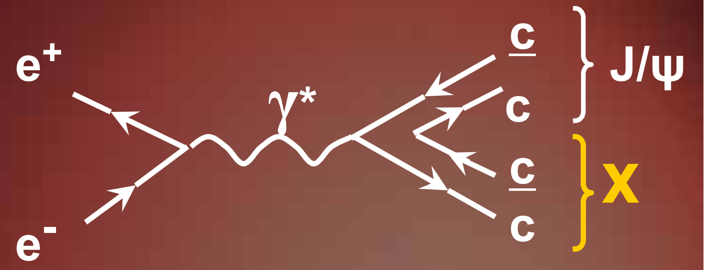
Maiani, Polosa et al.
hep-ph/0707.3354

X_u [uc][$\bar{u}\bar{c}$]→ $\bar{D}^0D^0\pi^0$= X(3875)
X_d [dc][$\bar{d}\bar{c}$]→ J/Ψππ = X(3872)

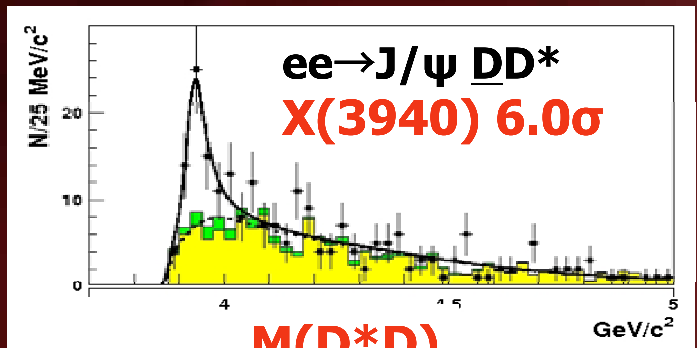
X(3940) and X(4160) in $e^+e^- \to J/\psi X_{c\bar{c}}$

PRL100, 202001 (2008)

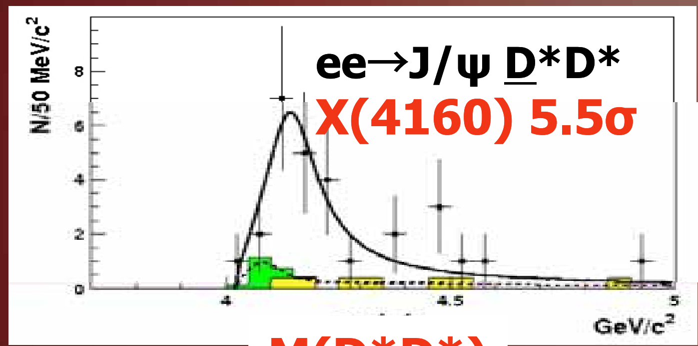
- x-sections much larger than QCD predicted
  → factory of 0^{++} and 0^{-+} charmonia



- Search for $X \to \bar{D}D^*$ and $\bar{D}^*D^*$ in $e^+e^- \to J/\psi \bar{D}^{(*)}D^*$



M(D*D)



M(D*D*)

$M = 3942^{+7}_{-6} \pm 6$ MeV
$\Gamma = 37^{+26}_{-15} \pm 12$ MeV

$M = 4156^{+25}_{-20} \pm 15$ MeV
$\Gamma = 139^{+111}_{-61} \pm 21$ MeV

$C_X = +1$ so
$X(4160) \neq \psi(4160)$

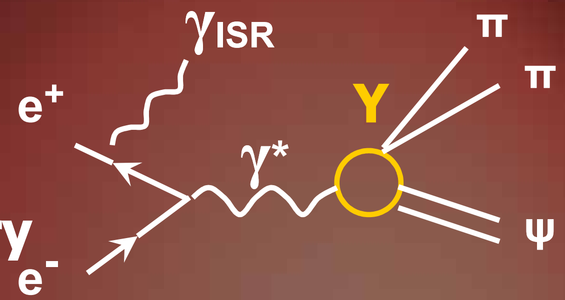
- Possible assignments: $\eta_c(3S)$ $\eta_c(4S)$
  (but X masses ~100-150MeV above predictions for η_c's)

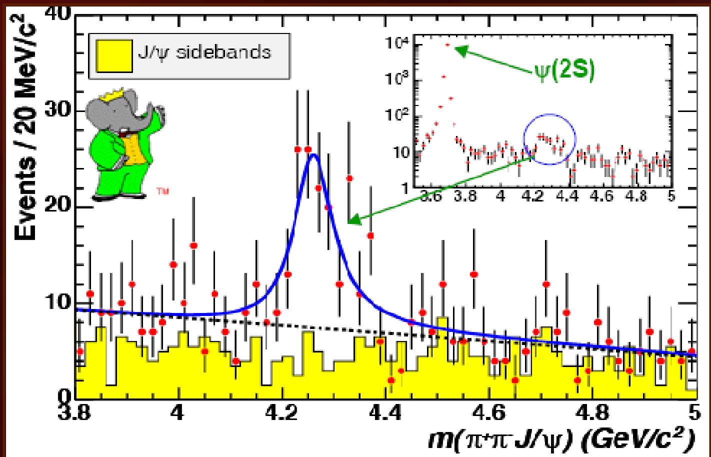
Y family through ISR

PRL 95, 142001 (2005) for 232fb-1

PRL 98, 212001 (2007) for 298fb-1

- **ISR gives access to $J^{PC}=1^{--}$ states**
- **Hard photon emission suppressed, ‘compensated’ by high luminosity of B-factory**

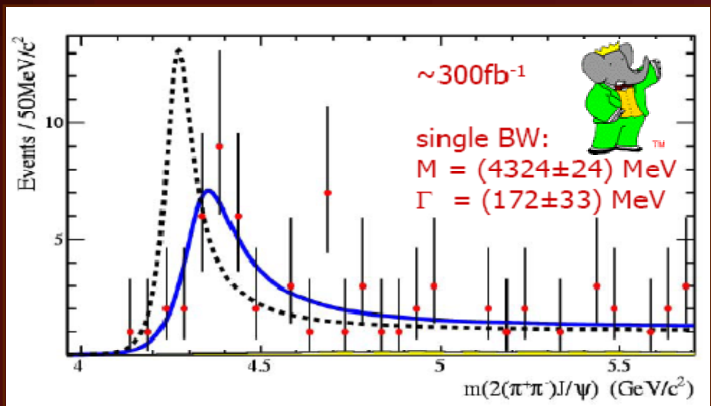




Y(4260)→J/ψππ

$M=4259 \pm 8^{+2}_{-6}$ MeV

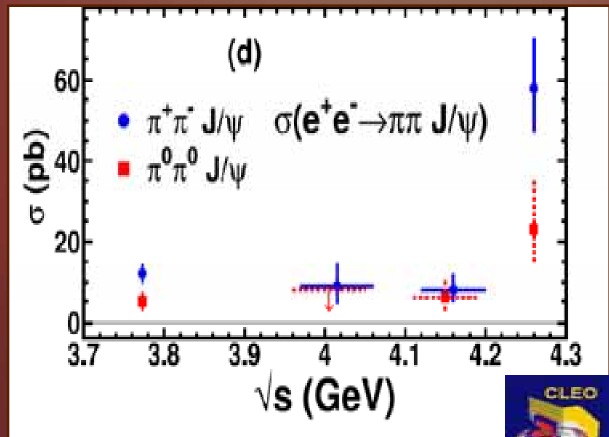
$\Gamma=88 \pm 23^{+6}_{-4}$ MeV



Y(4360)→ψ’ππ

$M=4324 \pm 24$ MeV

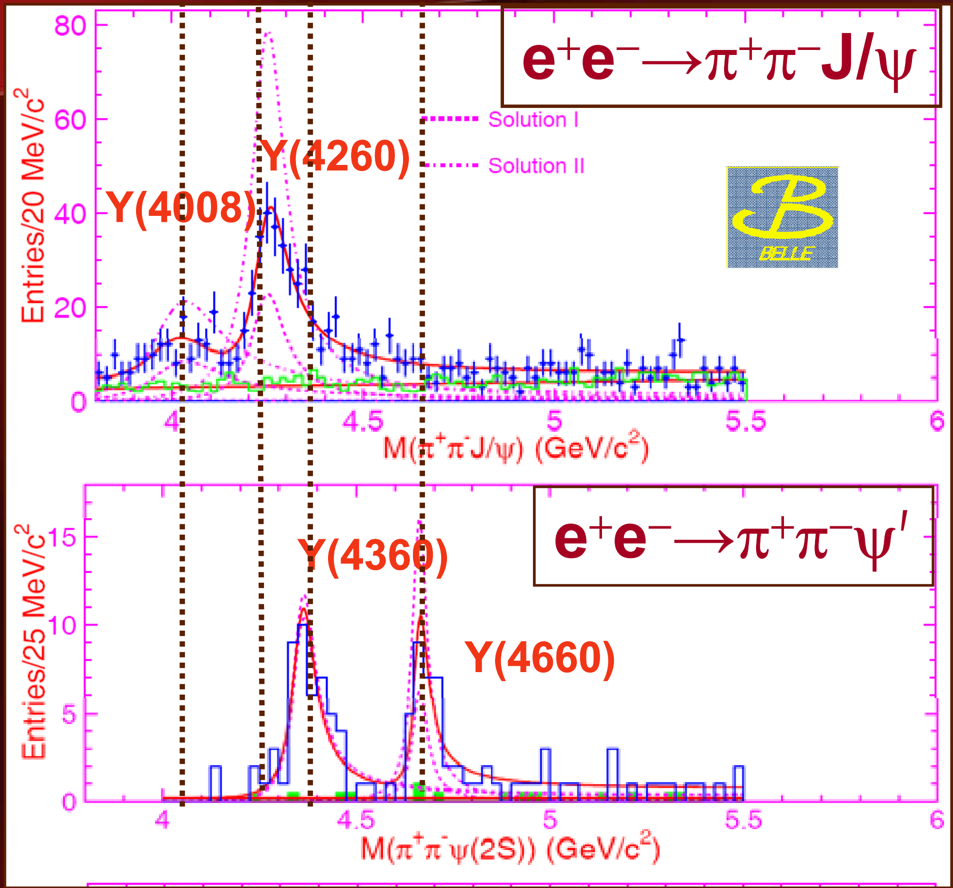
$\Gamma=172 \pm 33$ MeV



CLEO

PRD74, 091104 (2006)
PRL 96, 162003 (2006)
for $13pb^{-1}$@4.26GeV

1^{--} Y→ψππ states via ISR



- Y(4008), Y(4260), Y(4360), Y(4660)
- More 1^- states than empty slots in $c\underline{c}$ spectrum

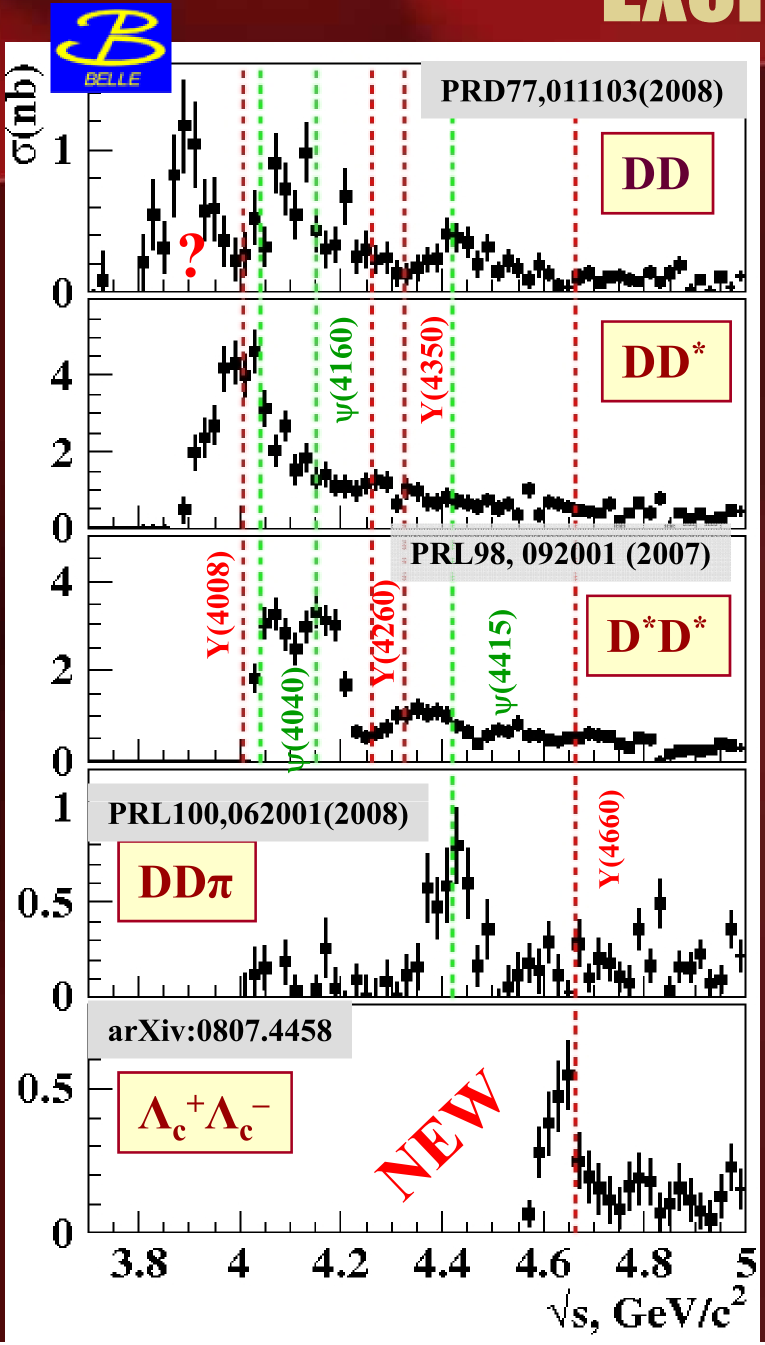
Unusual properties:

- Large widths for ψππ transition: unlike for conventional $c\underline{c}$
- Above $D\underline{D}$ threshold
  but don't match the peaks in $D^{(*)}D^{(*)}$ x-sections

Other options:

- $D\underline{D}_1$ or $D^*\underline{D}_0$ molecules
- $cq\underline{cq}$ tetraquarks
- ccg hybrid:
  $D\underline{D}_1$ decay mode should dominate
- Coupled-channel effects
- Charm-meson threshold effects

Exclusive x-sections with ISR



PRD 77, 011103 (2008) for 673fb^{-1}

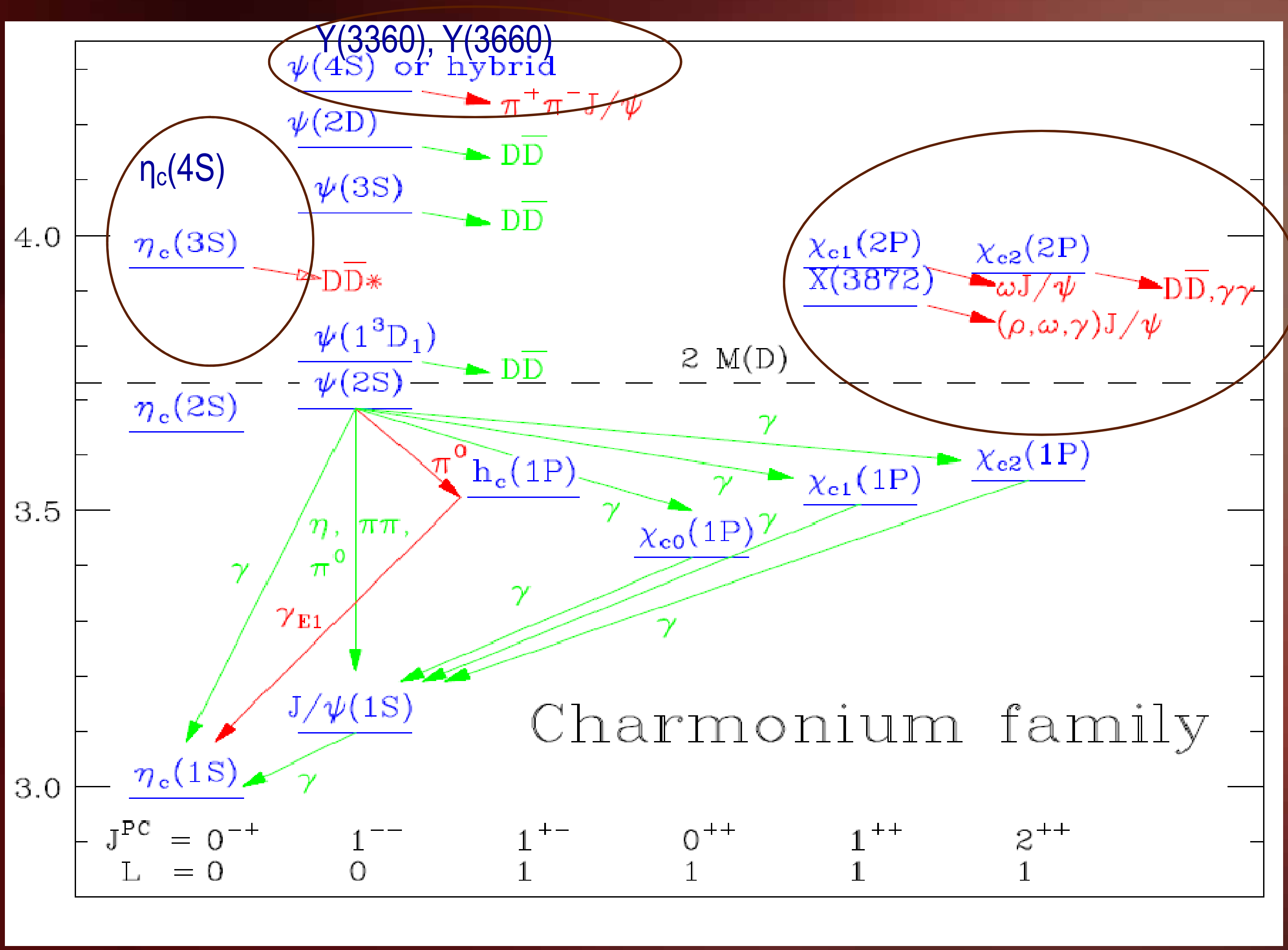
PRL 98, 092001 (2007) for 548fb^{-1}

PRL 100, 062001 (2008) for 673fb^{-1}

- **Difficult interpretation in terms of resonances (model dependent coupled-channel and threshold effects…)**

$c\underline{c}$ (-like) state of art

- We have observed a few new states
- Most of them don't match $c\underline{c}$ spectrum



$b\bar{b}$ analog of Y(4260)?

PRL100, 112001(2008)

- If $b\bar{b}$ follows the $c\bar{c}$ pattern: $Y_b \to Y(nS)\pi\pi$ with large partial width
- Study of **$Y(mS) \to Y(nS)\pi^+\pi^-$** with data at Y(5S)~10.87GeV (21.7/fb)

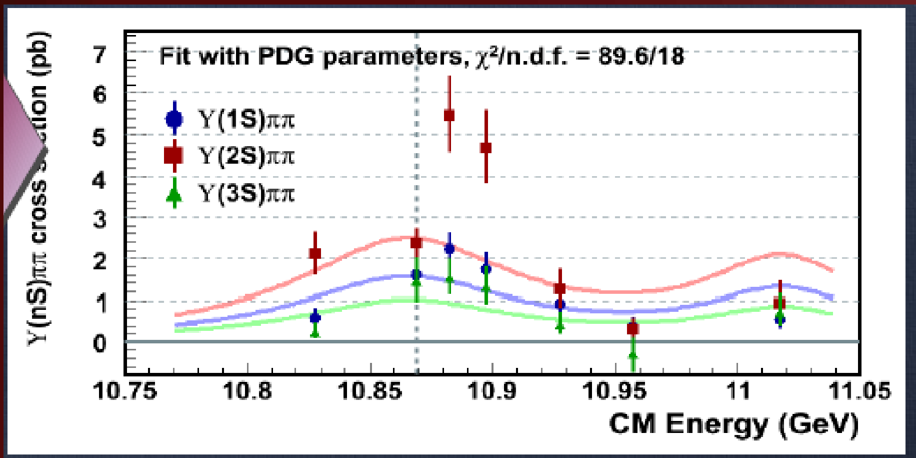
Process	Γ (MeV)
"Y(5S)"→Y(1S)ππ	0.59±0.04±0.09
"Y(5S)"→Y(2S)ππ	0.85±0.07±0.16
"Y(5S)"→Y(3S)ππ	$0.52^{+0.20}_{-0.17}$±0.10

Large Γ(Y(5S)→Y(nS)ππ)!

or other $b\bar{b}$ states: Γ~O(keV)

Is it Y_b? Mixture of Y(5S) and Y_b?

- Energy scan around Y(5S) (7.9/fb)



Observed shape disagree with Y(5S) hypothesis (fit).

Yb at 10.89GeV?

Summary

- New charmonium spectroscopy @4GeV
- Candidates for exotic hadrons observed:

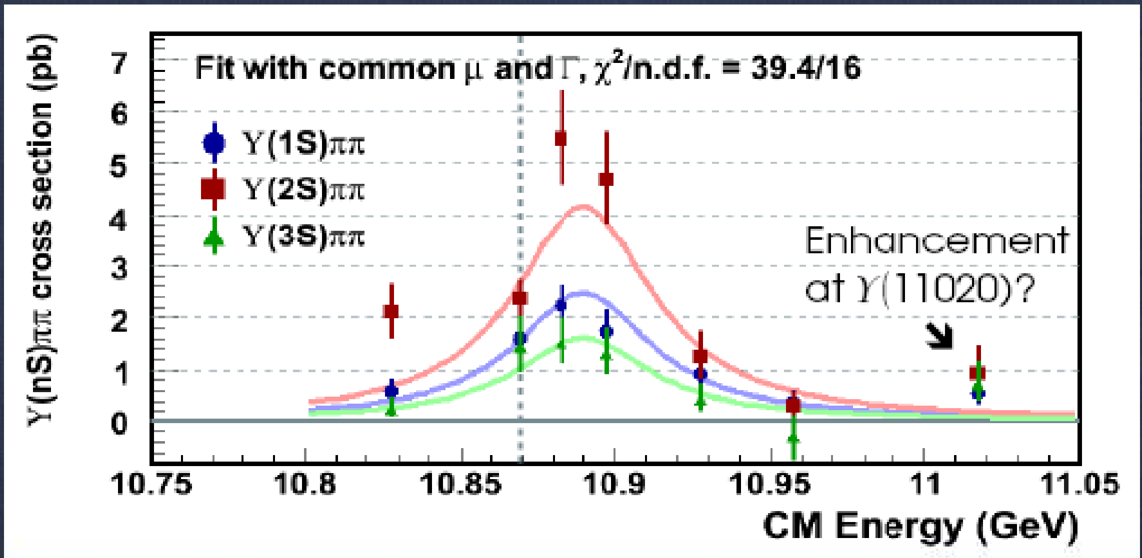
  $Z^+(4430) \rightarrow \psi' \pi^+$ $Z^+(4050)$, $Z^+(4248) \rightarrow \chi_{c1} \pi^+$
- Many other states await understanding

  X(3872) Y(3940) Y-family…
- Y_b? New spectroscopy also in b quark sectors?
- Theory input needed (models to verify, threshold effects, coupled channel effects)

Backup

$\Upsilon(nS)\pi\pi$ Resonant Shapes

- A χ^2 fit to the measured cross sections:
  (7 energies x 3 states = 21 points)



A common Breit-Wigner (floated mean & width) with floated 3 normalizations (for 1S, 2S, and 3S).

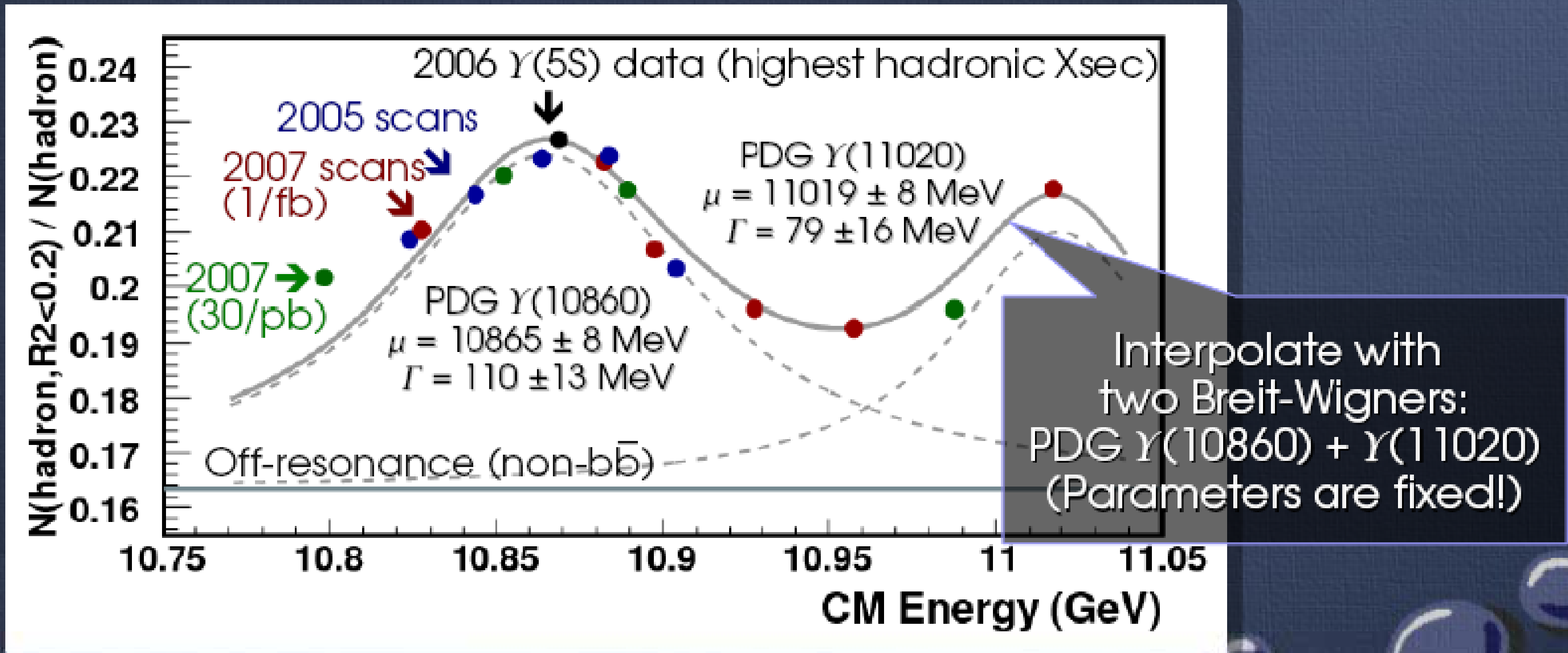
The mean value is ~20 MeV higher than the $\Upsilon(10860)$, and the width is around half (110 MeV → 55 MeV)!

	$\Upsilon(1S)\pi\pi$	$\Upsilon(2S)\pi\pi$	$\Upsilon(3S)\pi\pi$
Peak	$2.46^{+0.27}_{-0.25} \pm 0.18$ pb	$4.18^{+0.49}_{-0.46} \pm 0.55$ pb	$1.61^{+0.31}_{-0.28} \pm 0.21$ pb
Mean		$10889.6 \pm 1.8 \pm 1.5$ MeV	
Width		$54.7^{+8.5}_{-7.2} \pm 2.5$ MeV	

(Peak cross section for $\Upsilon(5S)$ is around 300 pb)

Compare with PDG $\Upsilon(5S)$ Parameters

- The observed hadronic ratios are consistent with the PDG two Breit-Wigner interpretation:

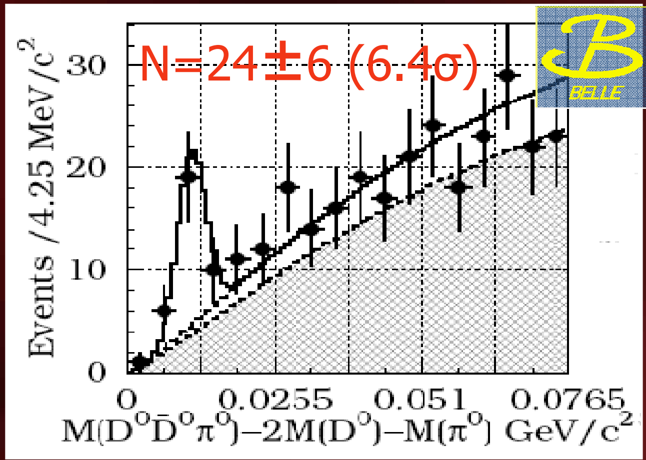


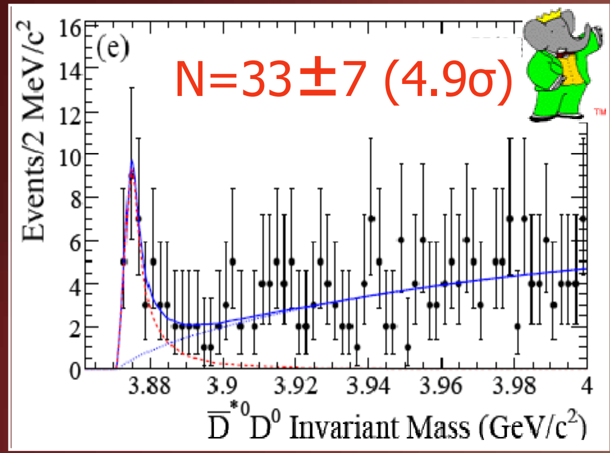
If we float the shapes for $\Upsilon(10860)$, a fit to these points yields μ ~ 10861 MeV & Γ ~ 107 MeV, are consistent with PDG values.

$X(3872) \to D^0\bar{D}^{*0}$ (?)

- **Belle: $B^+ \to \bar{D}^0 D^0 \pi^0 K$ (447M $B\bar{B}$) BaBar: $B^+ \to \bar{D}^{*0} D^0 K$ (383M$B\bar{B}$)**

PRL97, 162002(2006)





PRD77, 011102(2008)

$M(X)=3875.4 \pm 0.7^{+0.4}_{-1.7} \pm 0.9$ MeV

$M(X)=3875.1^{+0.7}_{-0.5} \pm 0.5$ MeV

$\Gamma=3.0^{+1.9}_{-1.4} \pm 0.9$ MeV

$$\frac{BR(X \to D^0\bar{D}^0\pi^0)}{BR(X \to J/\psi\pi^+\pi^-)} \sim 10$$

- **Mass ~4σ above M(X) for $X \to J/\psi\pi\pi$**
- **Is this X(3872) or are there two states X(3872) and X(3875)?**
- **More precise measurement of mass/width/line shape needed**

Maiani, Polosa et al.
hep-ph/0707.3354

X_u [uc][$\bar{u}\bar{c}$]→ $\bar{D}^0 D^0 \pi^0$ = X(3875)

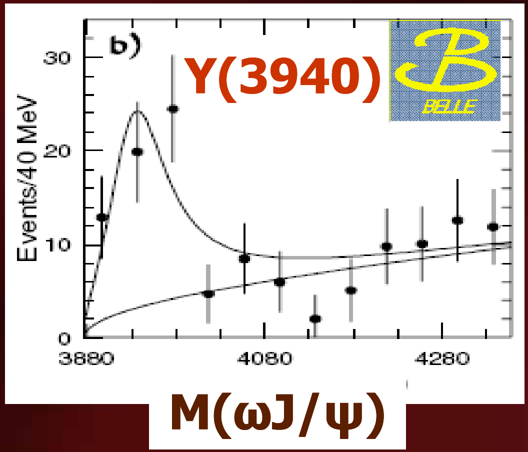
X_d [dc][$\bar{d}\bar{c}$]→ $J/\Psi\pi^+\pi^-$ = X(3872)

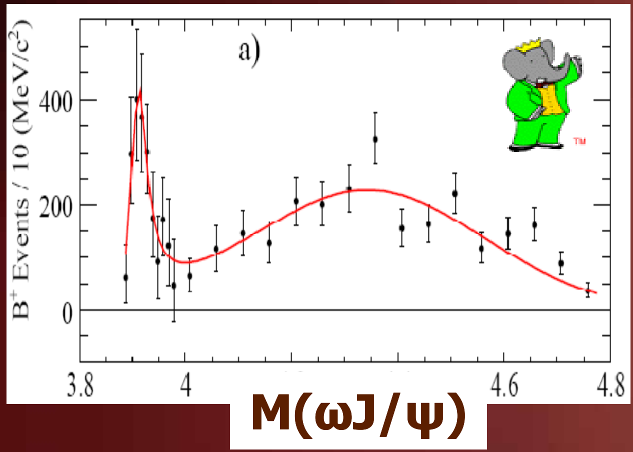
Y(3940)→J/ψω

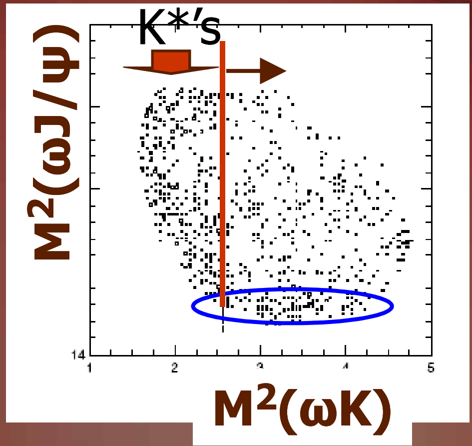
Belle PRL 94, 182002 (2005)

Babar hep-ex/0711.2047 submitted to PRL

- **Study of B→ KJ/ψω $\omega \to \pi^+\pi^-\pi^0$**
- **M_{bc} , ΔE and $M(\pi^+\pi^-\pi^0)$ selection**







BF(B→KY)*BF(Y→J/ψω)=

Belle (7.1±1.3±3.1)*10⁻⁵

Babar (4.9±1.0±0.5)*10⁻⁵

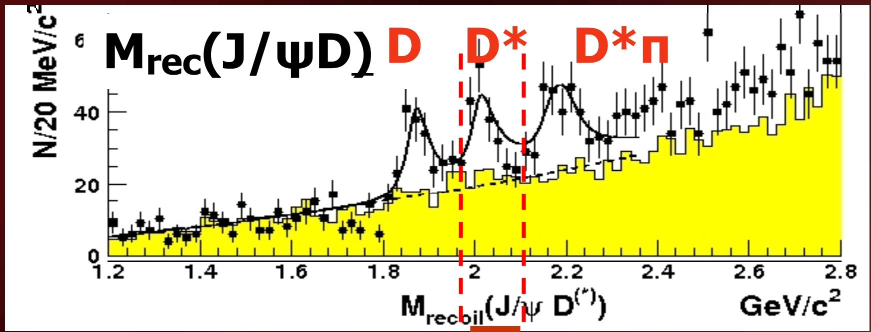
	Mass (MeV)	Γ (MeV)
Belle 253 fb^{-1}	$3943 \pm 11(stat) \pm 13(syst)$	$87 \pm 22(stat) \pm 26(syst)$
BaBar 350 fb^{-1}	$3914.3^{+3.8}_{-3.4}(stat)^{+1.6}_{-1.6}(syst)$	$33^{+12}_{-8}(stat)^{+0.6}_{-0.6}(syst)$

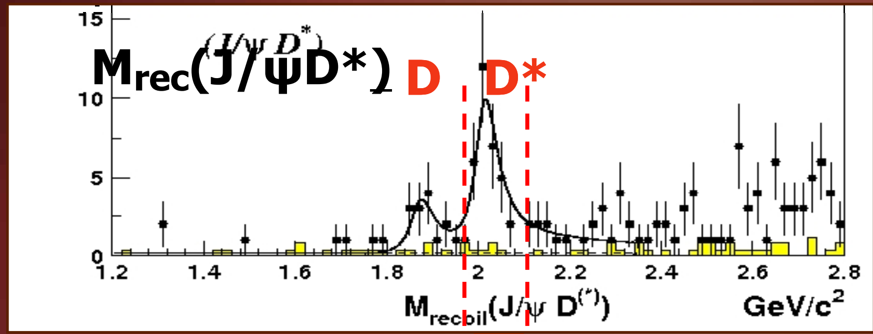
mass/width discrepancy needs further study

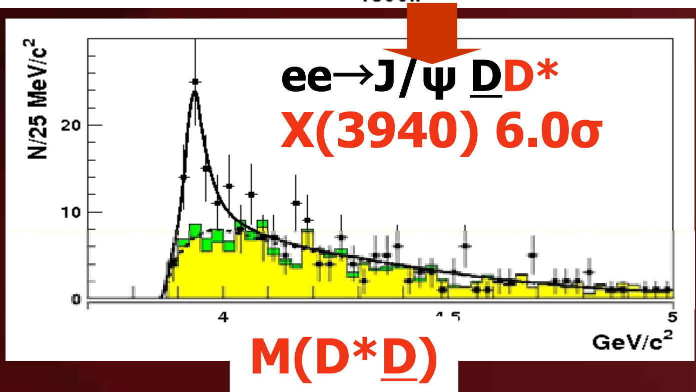
- **Y(3940) above D$\bar{D}$ threshold but has large c$\bar{c}$ transition**
- **Candidate for c$\bar{c}$-gluon hybrid? (but hybrids predicted >4GeV)**
- **Re-scattering D$\bar{D}$*→J/ψω?**

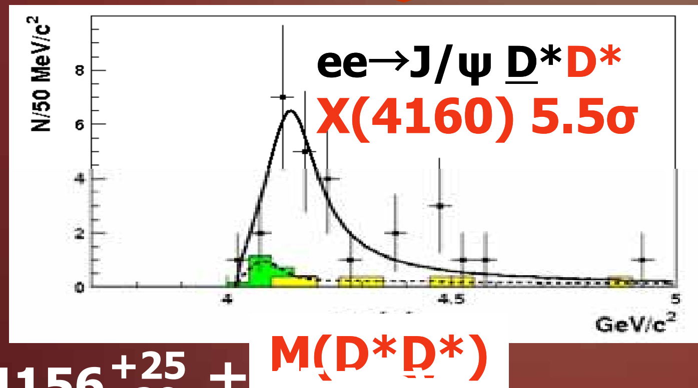
PRL100, 202001 (2008) $X(3940)\to D\underline{D}^*$ and $X(4160)\to D^*\underline{D}^*$

- Reconstruct J/ψ and one $D^{(*)}$, associated $D^{(*)}$ seen as peak in $M_{recoil}(J/\psi D^{(*)})$









$M = 3942^{+7}_{-6} \pm 6$ MeV

$\Gamma = 37^{+26}_{-15} \pm 12$ MeV

$M = 4156^{+25}_{-20} \pm 15$ MeV

$\Gamma = 139^{+111}_{-61} \pm 21$ MeV

$C_X = +1$ so $X(4160) \neq \psi(4160)$

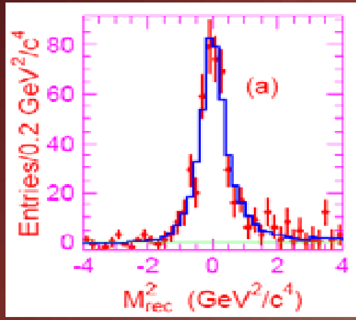
- Possible assignments: $\eta_c(3S)$ $\eta_c(4S)$

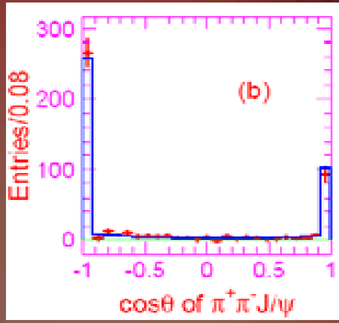
(but X masses ~100-150MeV above predictions for η_c's)

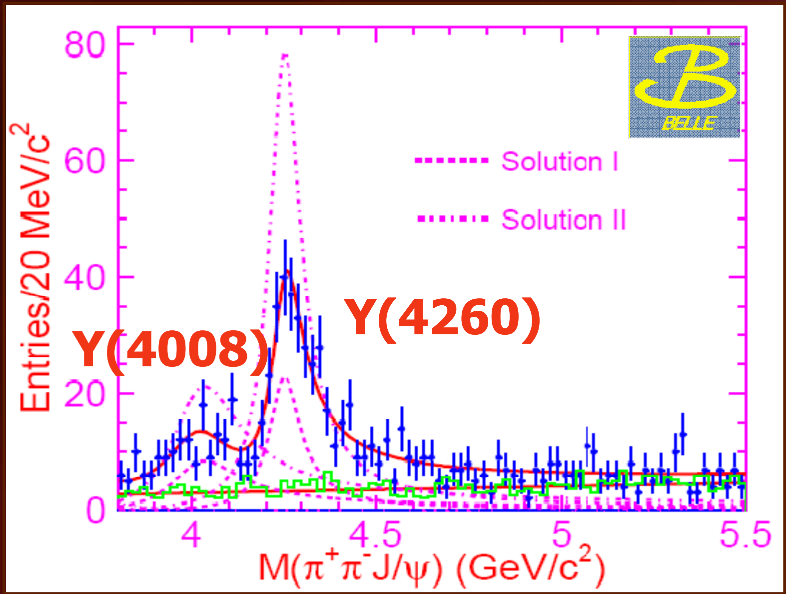
Y→J/ψππ via ISR

PRL 99, 182004 (2007)

- Study of $e^+e^- \to J/\psi \pi^+\pi^- \gamma_{ISR}$ (548 fb^{-1})
- $J/\psi \to ee, \mu\mu + \pi\pi$; no extra tracks
- ISR photon is not detected
- Missing mass used to identify process







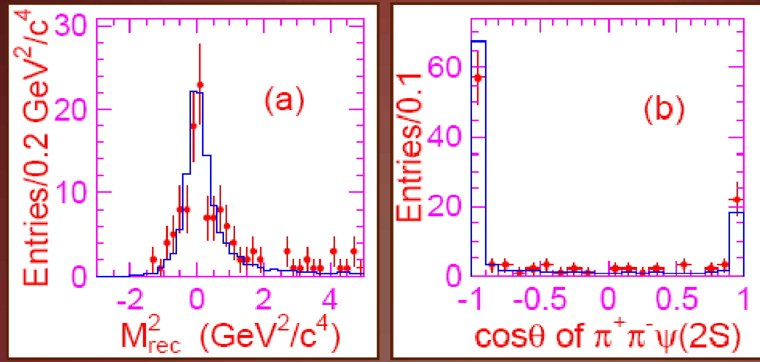
Parameters	Solution I	Solution II
$M(R1)$	$4008 \pm 40^{+114}_{-28}$	
$\Gamma_{tot}(R1)$	$226 \pm 44 \pm 87$	
$\mathcal{B} \cdot \Gamma_{e^+e^-}(R1)$	$5.0 \pm 1.4^{+6.1}_{-0.9}$	$12.4 \pm 2.4^{+14.8}_{-1.1}$
$M(R2)$	$4247 \pm 12^{+17}_{-32}$	
$\Gamma_{tot}(R2)$	$108 \pm 19 \pm 10$	
$\mathcal{B} \cdot \Gamma_{e^+e^-}(R2)$	$6.0 \pm 1.2^{+4.7}_{-0.5}$	$20.6 \pm 2.3^{+9.1}_{-1.7}$
ϕ	$12 \pm 29^{+7}_{-98}$	$-111 \pm 7^{+28}_{-31}$

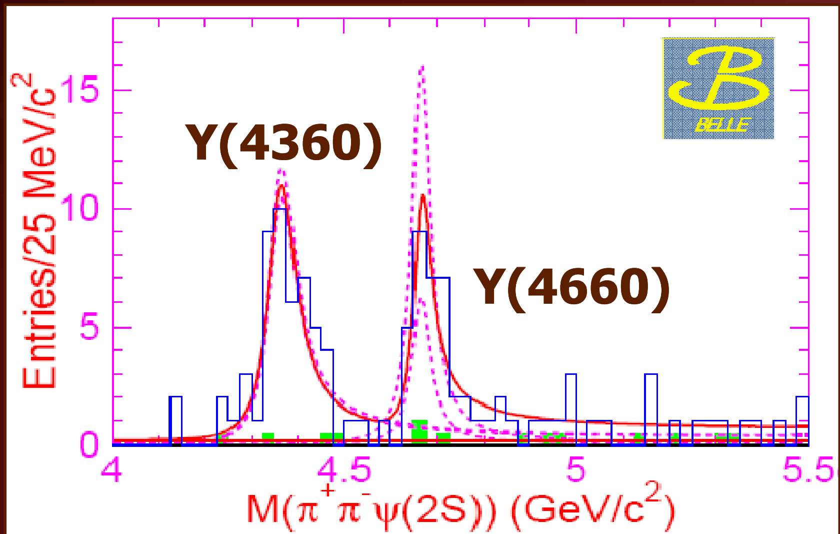
- Y(4260) confirmed
- Y(4008) resonance? Re-scattering from DD*? Coupled-channel effect?

Y→ψ'ππ via ISR

PRL 99, 142002 (2007)

- **Study of $e^+e^-\to\psi'\pi^+\pi^-\gamma_{ISR}$ (673 fb^{-1})**
- **$\psi'\to J/\psi\pi\pi$, $J/\psi\to ee$, $\mu\mu$ + ππ**
- **no additional tracks allowed**
- **γ_{ISR} not detected**
- **Two significant peaks in M(ψ'ππ) :**
  one close to Babar's Y(4360) but narrower
- **M(ψ'ππ) fitted with two coherent Breit-Wigners**

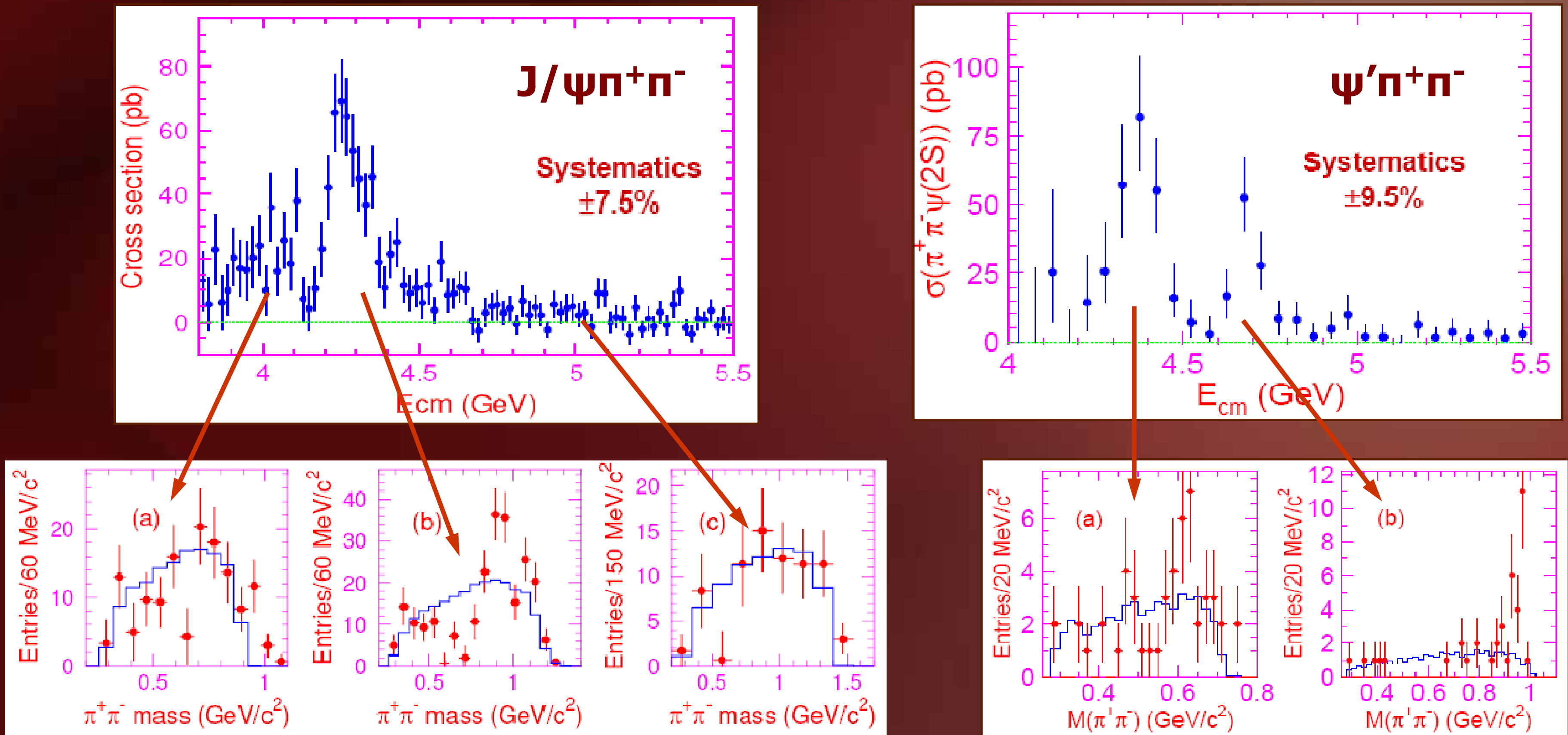




Parameters	Solution I	Solution II
$M(Y(4360))$	$4361 \pm 9 \pm 9$	
$\Gamma_{tot}(Y(4360))$	$74 \pm 15 \pm 10$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(Y(4360))$	$10.4 \pm 1.7 \pm 1.5$	$11.8 \pm 1.8 \pm 1.4$
$M(Y(4660))$	$4664 \pm 11 \pm 5$	
$\Gamma_{tot}(Y(4660))$	$48 \pm 15 \pm 3$	
$\mathcal{B}\cdot\Gamma_{e^+e^-}(Y(4660))$	$3.0 \pm 0.9 \pm 0.3$	$7.6 \pm 1.8 \pm 0.8$
ϕ	$39 \pm 30 \pm 22$	$-79 \pm 17 \pm 20$

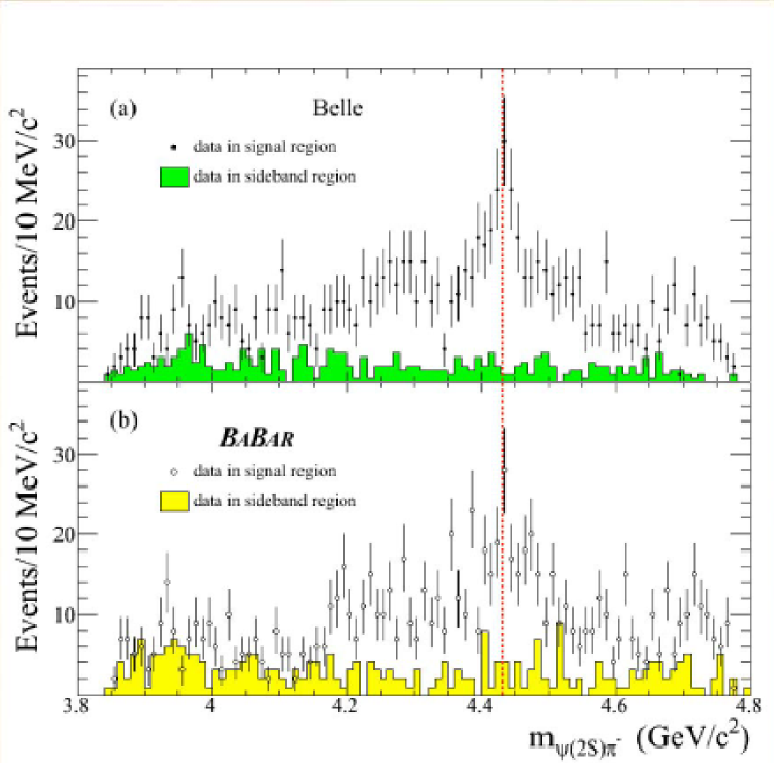
x-sections for $e^+e^- \to \psi\pi\pi$

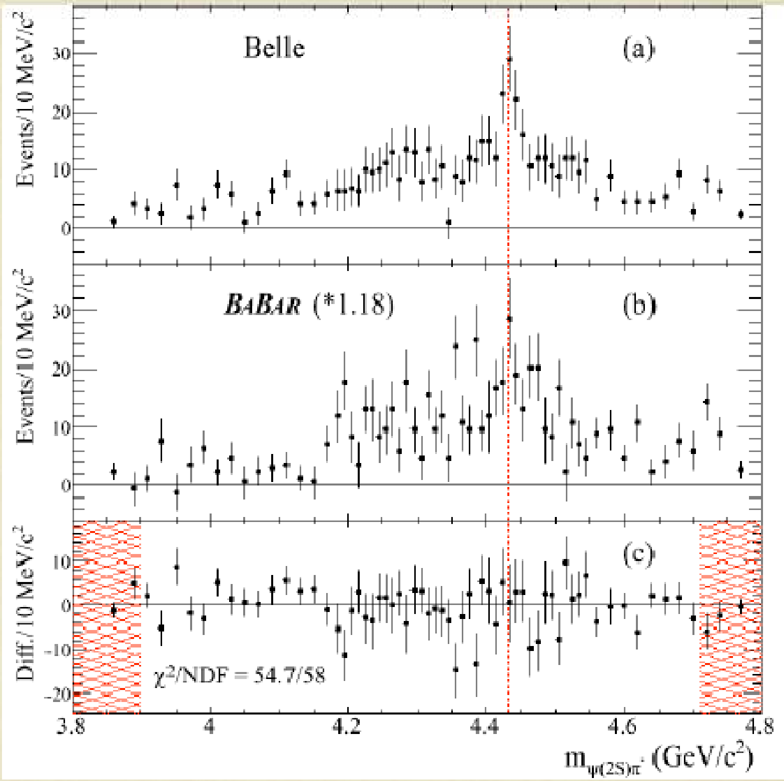
- **ISR allows us to measure hadronic x-sections in wide energy range: model independent measurement**
- **M(ψππ): background subtracted, corrected for efficiency and luminosity → Cross-section for $e^+e^- \to \psi\pi^+\pi^-$**



BELLE-BABAR COMPARISON

Not applied efficiency correction to the data and applying the K* veto

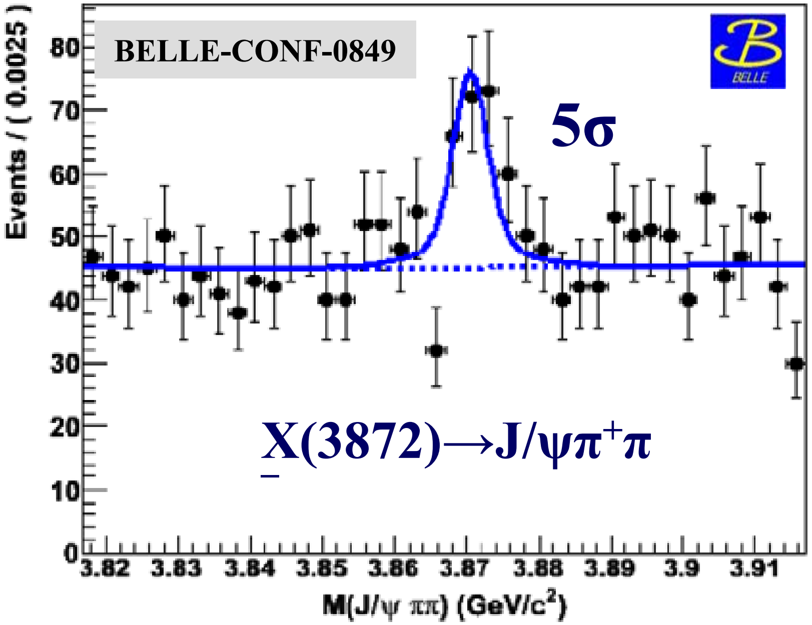




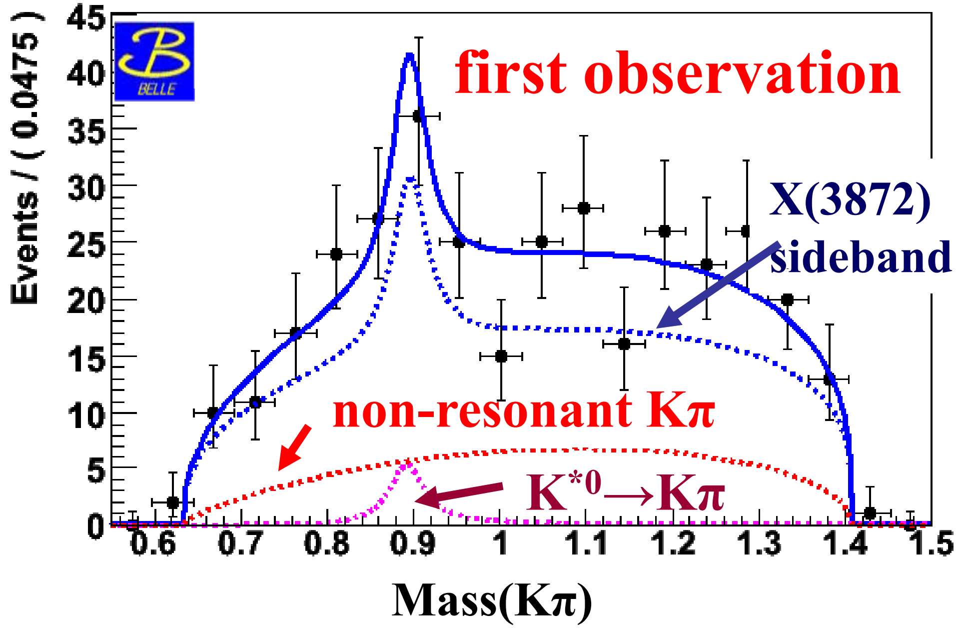
Both Belle and *BABAR* data are re-binned (to calculate χ^2) and side-band subtracted

The *BABAR* data are normalized to the Belle sample.

The data distributions are statistically consistent (χ^2=54.7/58)



$B^0 \to X(3872) K^+ \pi^-$



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

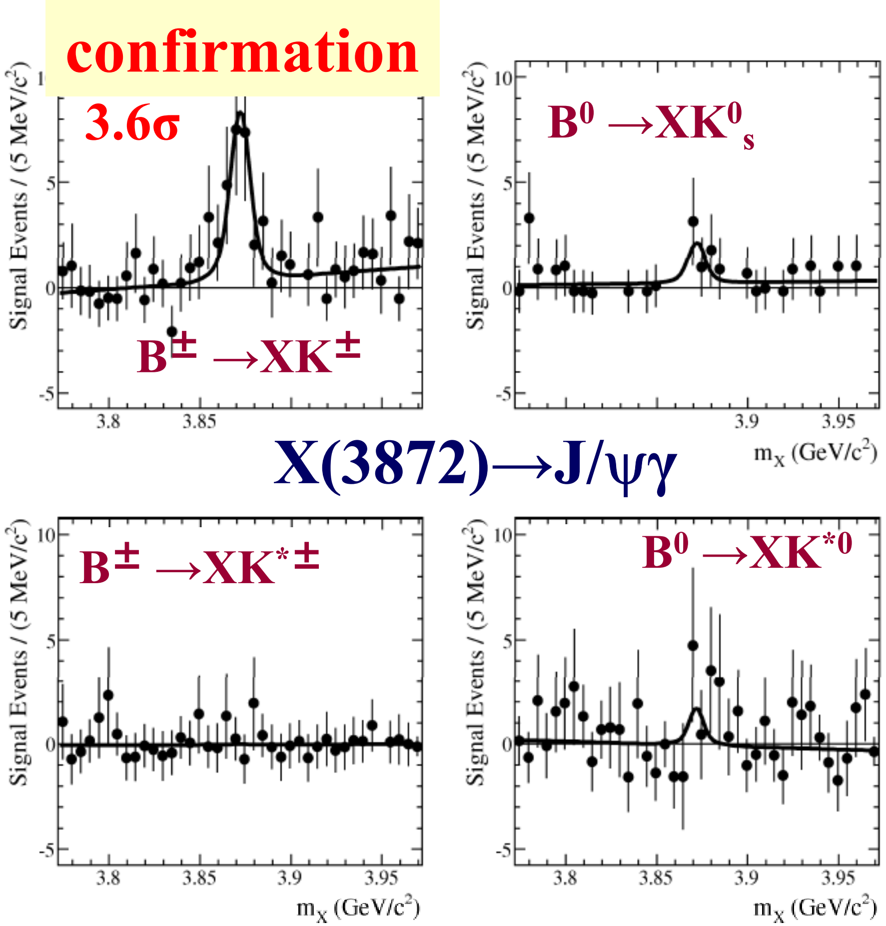
dominates ! unlike $B \to K$"$c\bar{c}$"

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

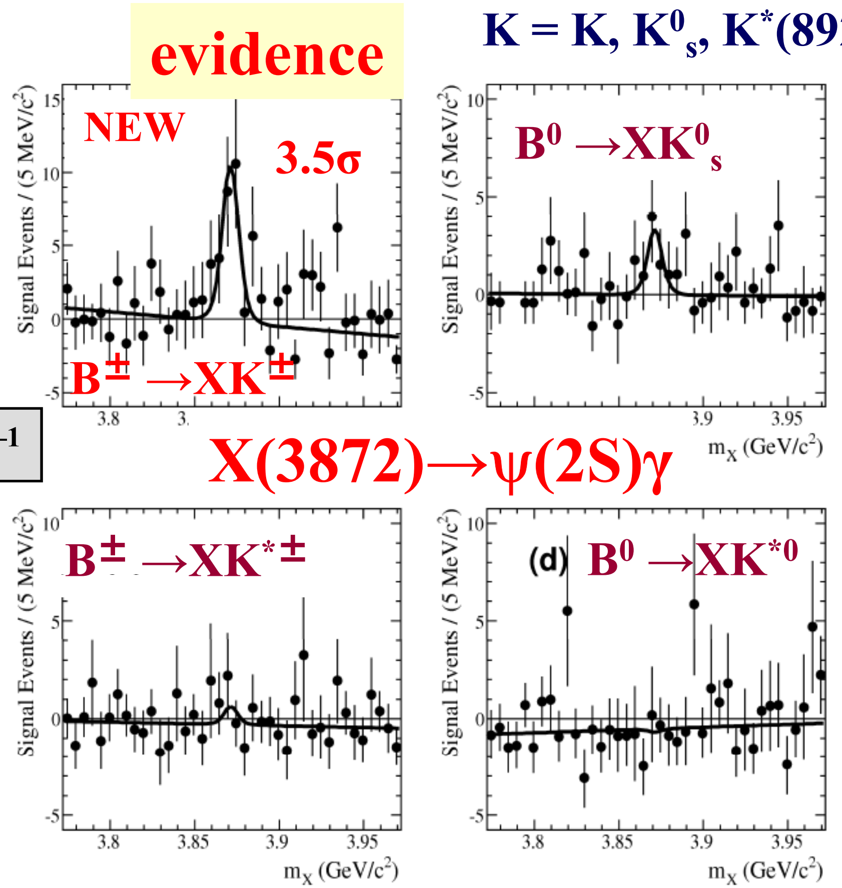
$$\frac{Br(B^0 \to X(K^+\pi^-)_{non\ res})}{Br(B^0 \to X K^0_s)} \sim 1$$

$B \to J/\psi\gamma K$ & $B \to \psi(2S)\gamma K$

$K = K, K^0_s, K^*(892)$



424fb^{-1}



$(B^\pm \to XK^\pm)Br(X \to J/\psi\gamma) = (2.8 \pm 0.8 \pm 0.2)10^{-6}$

$(B^\pm \to XK^\pm)Br(X \to \psi(2S)\gamma) = (9.9 \pm 2.9 \pm 0.6)10^{-6}$

$Br(X \to \psi(2S)\gamma) / Br(X \to J/\psi\gamma) = 3.5 \pm 1.4$

$Br(X \to \psi(2S)\gamma) / Br(X \to J/\psi\pi^+\pi^-) = 1.1 \pm 0.4$

Relatively large $Br(X \to \psi(2S)\gamma)$ is inconsistent with a pure $D^0\bar{D}^{*0}$ molecular interpretation for X(3872)

<u>Favors $c\bar{c}$ - $D^0\bar{D}^{*0}$ mixing models</u>

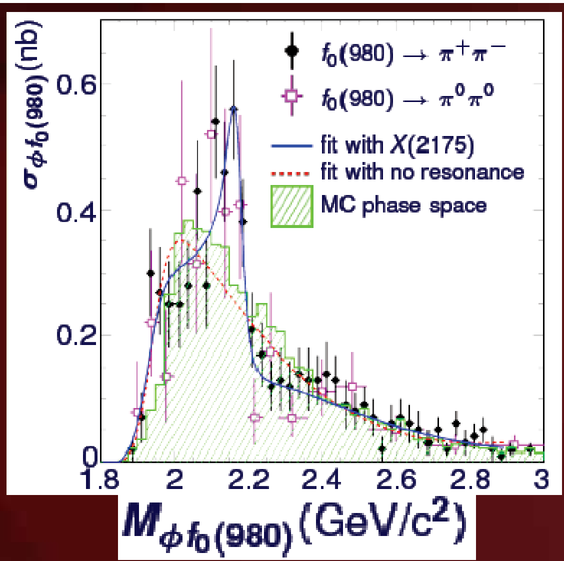
HQ session: Arafat G.Mokhtar

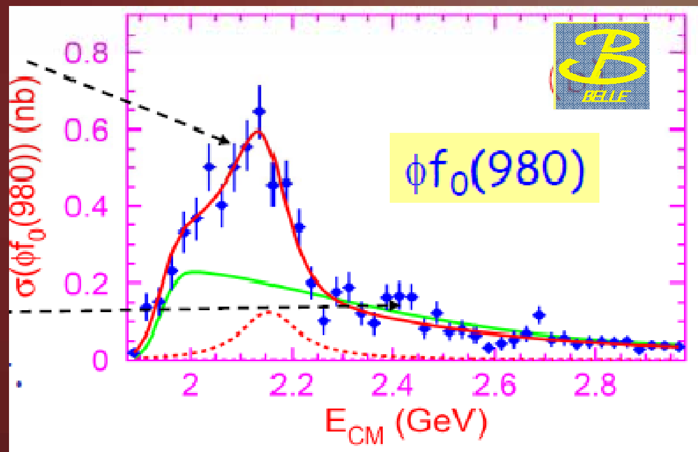
X(2175) strange analog of Y(4260)?

- **X(2175)→ φ f_0(980), φη (confirmed by BESII and Belle)**

$e^+e^- \rightarrow \gamma_{ISR}\ \phi(\rightarrow k^+k^-)\ f_{(980)}$

- ISR Process: $e^+e^- \rightarrow X(2175)\gamma_{ISR} \rightarrow \phi f_0(980)\gamma_{ISR}$
- $\phi \rightarrow K^+K^-$
- $f_0(980) \rightarrow \pi^+\pi^-, \pi^0\pi^0$
- Luminosity 232 fb^{-1}





$M(Y(2175))=(2133\ ^{+69}_{-115})$ MeV/c^2,
$\Gamma(Y(2175))=(169\ ^{+105}_{-92})$ MeV/c^2.

Parameters

$M_X = 2175 \pm 10$ MeV/c^2

$\Gamma_X = 58 \pm 16$ MeV

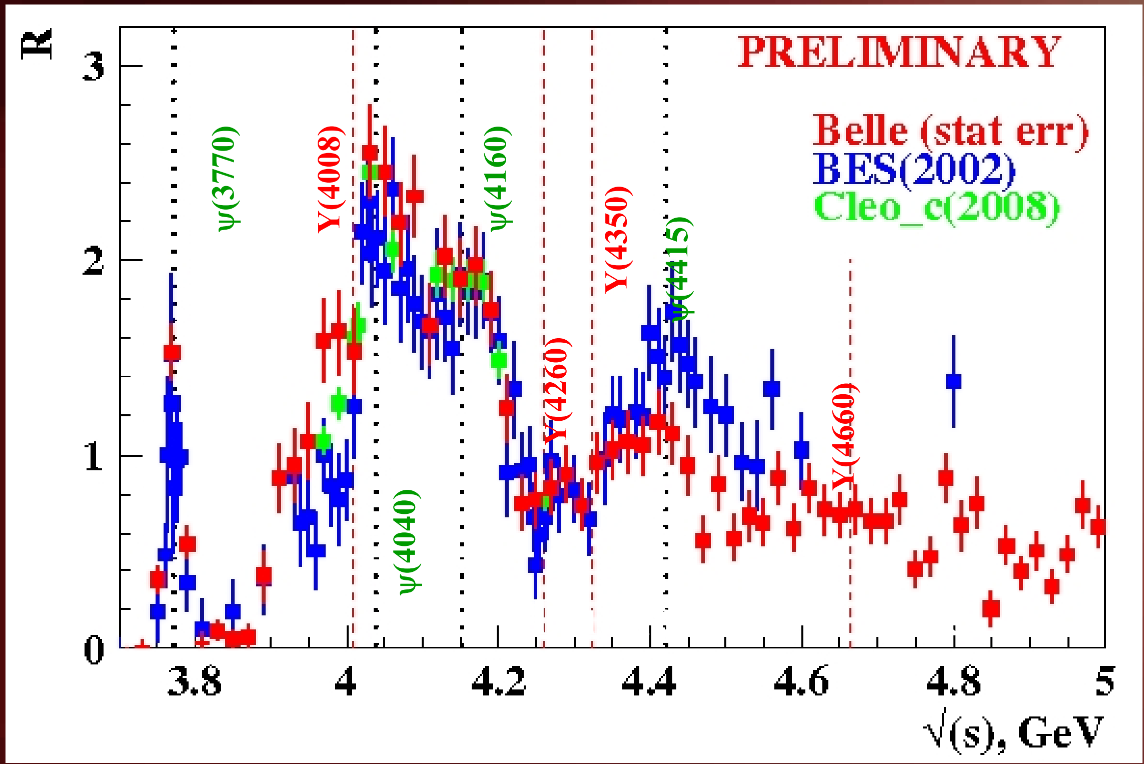
$\sigma(M_X) = 0.13 \pm 0.4$ nb

PRD74, 091103 (2006)

hep-ex/0808.0006

Hadronic x-sections

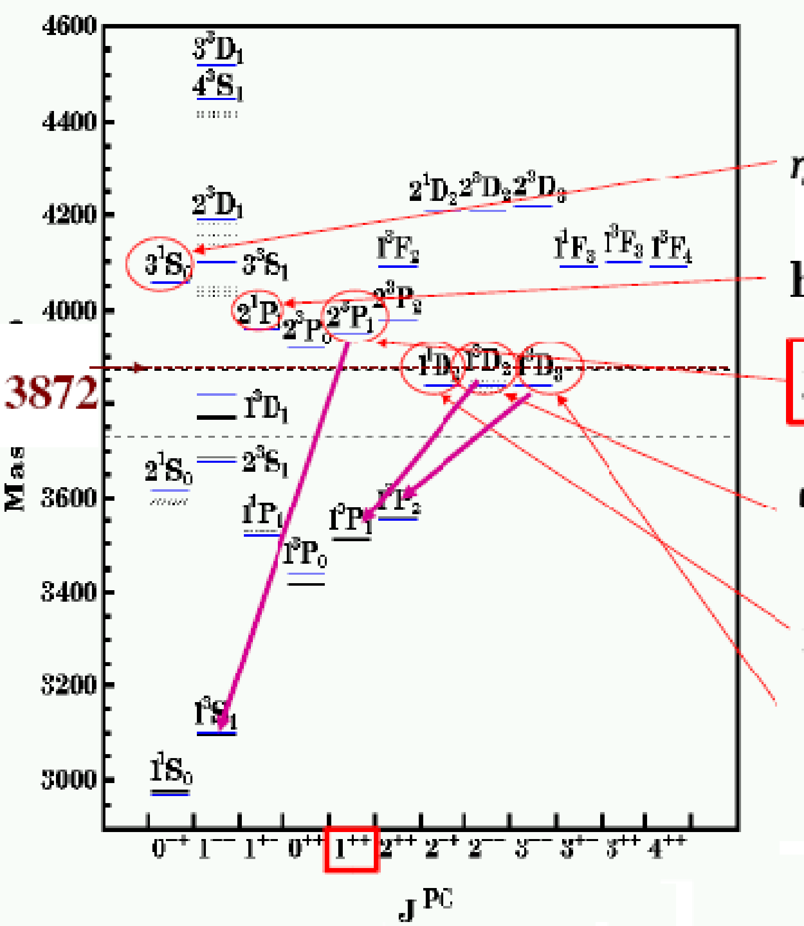
- From CLEO: scan at 3.97-4.26GeV in 12 points
- Total hadronic x-section above D$\underline{D}$ from BES
- Belle: sum of all measured exclusive contributions



Is X(3872) a $c\bar{c}$ state ?

No obvious $c\bar{c}$ assignment

if $J^{PC} = 1^{++}$



hep-ex/0407033

η_c'' M too low and Γ too small

h_c' angular dist rules out 1^{+-}

χ_{c1}' $\Gamma(\gamma J/\psi)$ way too small

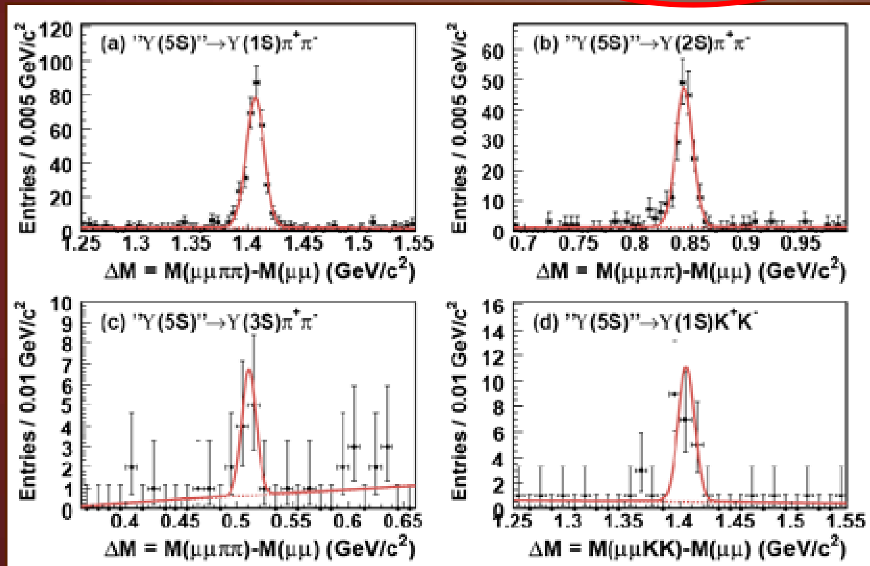
ψ_2 $\Gamma(\gamma \chi_{c1})$ too small
$M(\pi^+\pi^-)$ wrong

η_{c2} $\pi\pi\eta_c$ should dominate

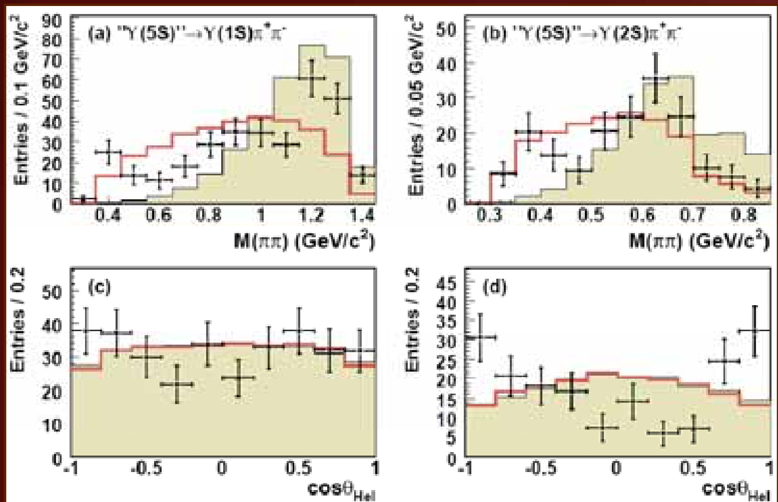
ψ_3 $\Gamma(\gamma \chi_{c2} \&\& D\bar{D})$ too small

Yb counterpart ?

Process	Yield	σ(pb)	BF(%)	Γ(MeV)
"Υ(5S)"→Υ(1S)ππ	325±20	1.6±0.1±0.1	0.53±0.03±0.05	0.59±0.04±0.0
"Υ(5S)"→Υ(2S)ππ	186±15	2.3±0.2±0.3	0.78±0.06±0.11	0.85±0.07±0.1
"Υ(5S)"→Υ(3S)ππ	10±4	1.4±0.5±0.2	0.48±0.18±0.07	0.52±0.20±0.1



- M(ππ) and $\cos\theta_{hel}$ studied



Brown-Cahn (CLEO) model (grey)
generic phase space (open)

How to identify B meson signal

- Advantage of $e^+e^- \to \Upsilon(4S) \to B\underline{B}$ kinematics:

  $m_{\Upsilon(4S)} \sim m_B + m_{\underline{B}}$ no accompanying particles

  $\to$ $E_B = E_{beam} = \sqrt{s}/2$ in Υ cms
- kinematical variables used in B-Factories

  $M_{bc} = \sqrt{E^2_{beam} - p^2_B}$

  beam-constrained mass

  (signal at $m_B \sim 5.28$GeV)

  $\Delta E = E_B - E_{beam}$

  cms energy difference

  (signal peaks at 0)

- Resolution improvement

  (E_{beam} is precisely known)
- Background separation