X International Conference of Heavy Quarks and Leptons

11-15 October, 2010, Frascati (Italy)

Spectroscopy results

from

BaBar

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Outline

- Introduction
- Motivations
- X, Y, Z particles from Y(*4s*)
- $e^+e^- \rightarrow \gamma_{ISR}$ Y **SUMMARY**
- D_n states
- $h_{b,}$ η_b
- Conclusions

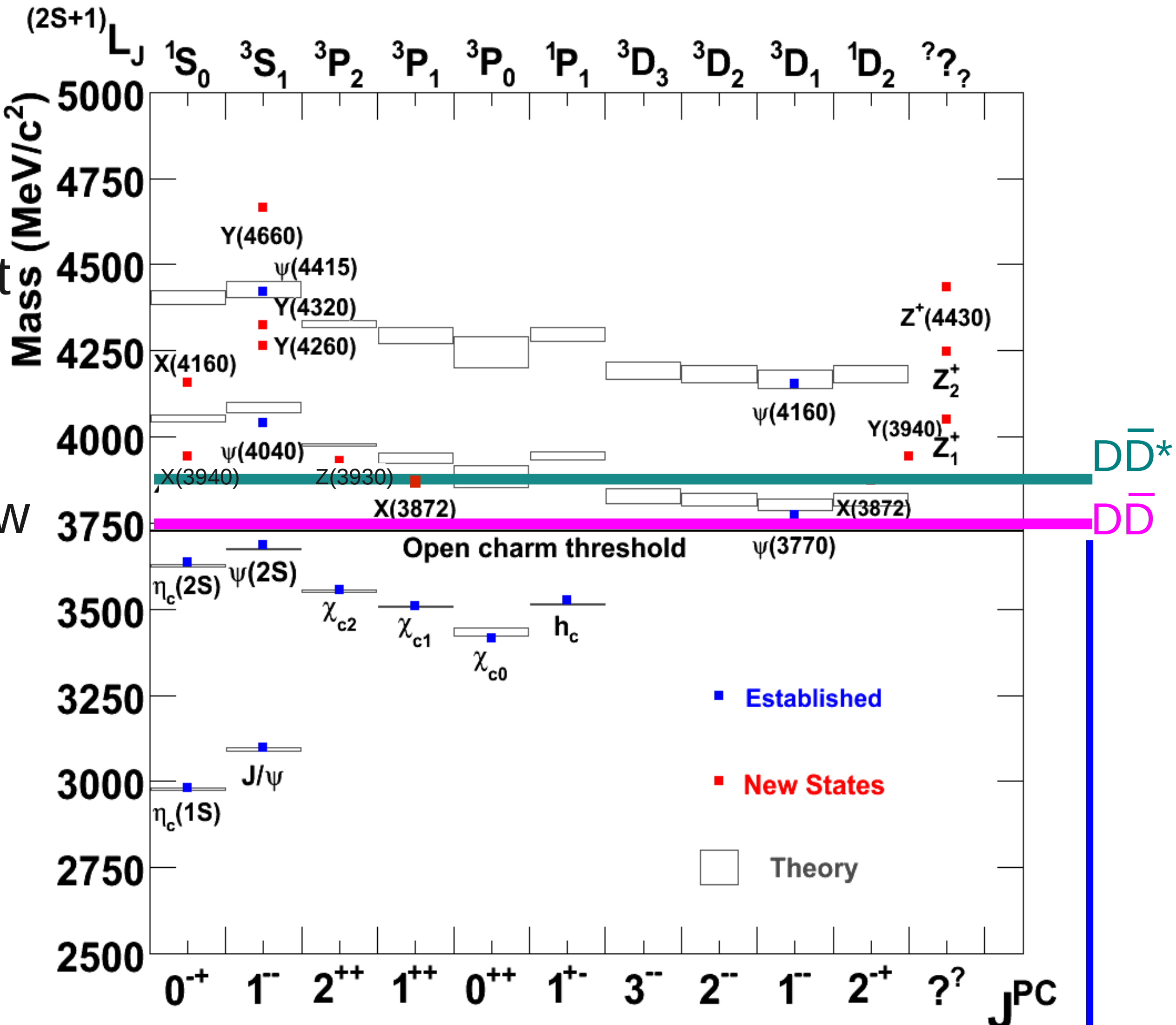
Introduction

- Recent observations of (unexpected) new states have been performed.

- Several resonances do not fit theoretical predictions.

- Many subsequent interpretations of these new states and methods were suggested to analyze their structure (HQT, chiral symmetries, 4-quark models, bag model, Lattice...)

- The spectrum of Heavy Quarkonium states is an ideal place to provide precision tests of QCD.



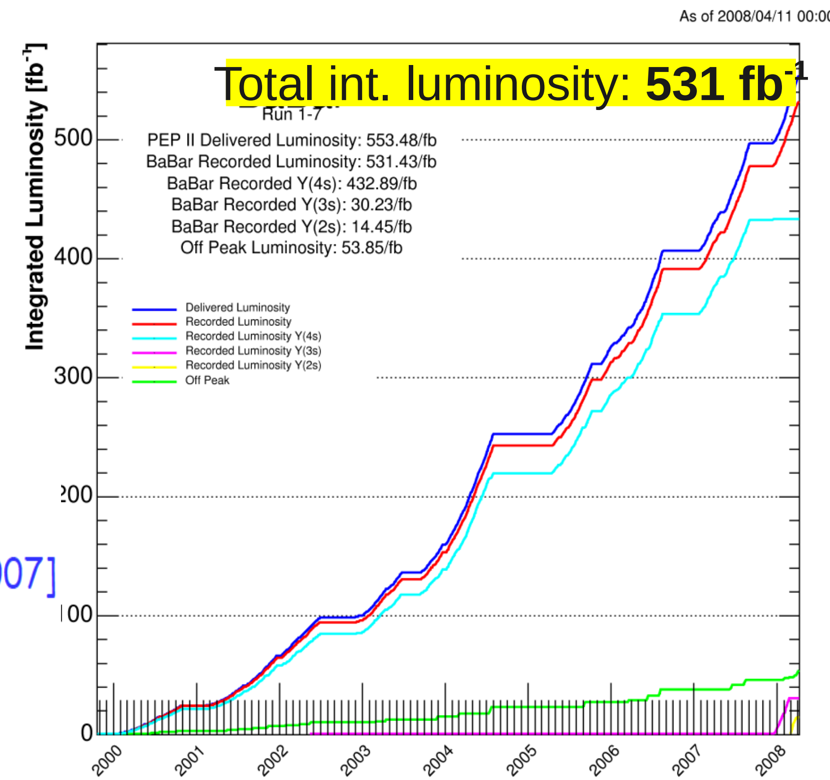
Motivations

- ***BaBar*** is a B-factory:

1999-2007 ☞ ~ 433fb^{-1} @ Υ(4S) (on-peak data)
end of Dec07- end of Feb08 ☞ 30fb^{-1} @ Υ(3S)
end of Feb08-6th of April08 ☞15fb^{-1} @ Υ(2S)
scan about Υ(4S) (25pb^{-1} every 5 MeV)

- The main goal of the BaBar Physics has been the measurement of the sides and angles of the Unitarity Triangle, and rare
- decays.

- B-factories have been demonstrated to be also a **huge source of $c\bar{c}$ production**. [$\sigma(e^+e^- \rightarrow c\bar{c})$ = 1.30 nb]



- CPV in B decays, CKM physics <u>~465x10^6 Υ(4S)→$B\bar{B}$ events</u>
- ~650x10^6 $e^+e^- \rightarrow c\bar{c}$ events: 1st observation of D^0-$\bar{D}^0$ mixing [2007]
- ~430x10^6 $e^+e^- \rightarrow \tau^+\tau^-$ events (360 x combined LEP sample): LFV
- ISR events: unique access to low energy e^+e^- cross sections

➨ SPECTROSCOPY

Spectroscopy

BABAR

- Production in continuum:
  - $e^+e^- \rightarrow J/\psi X$ (C_X=+)
  - $e^+e^- \rightarrow \gamma_{ISR} X$ (only $J^{PC}=1^{--}$)
- Production B decays:
  - $b \rightarrow c$ (color suppressed decay)
  - open-charm and charmonium
    ($c\bar{s}$ and $c\bar{c}$ meson, cqq baryons; $c\bar{c}$ +...)
  - $\gamma\gamma \rightarrow X$ ($J_X \neq 1$)

charm and charmonium spectroscopy

- Transition $Y(4S) \rightarrow Y(2S)\pi^+\pi^-$, $Y(4S) \rightarrow Y(1S)\pi^+\pi^-$, $Y(4S) \rightarrow Y(1S)\eta$

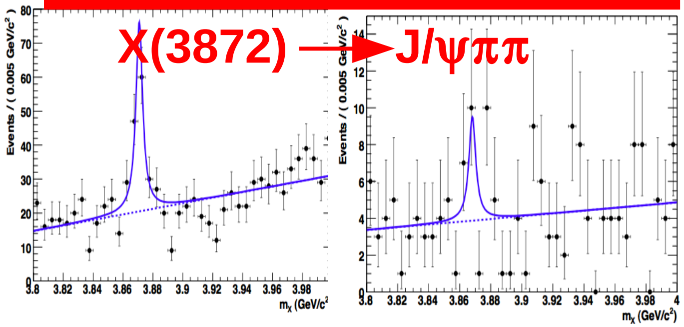
bottomonium spectroscopy

The main goal of the physics @***Y(3S)*** and ***@Y(2S)*** is the search of **bottomonium** states and **light Higgs.**

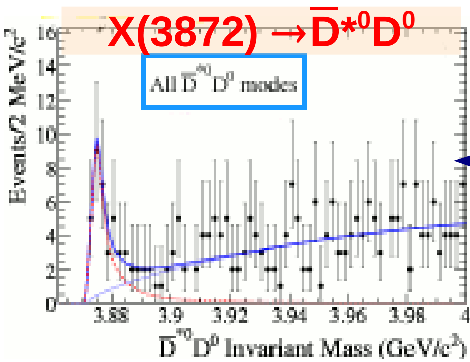
Summary of the main results: $B \to [X,Y]\, K$

BABAR

PRD 77, 111101(2008)

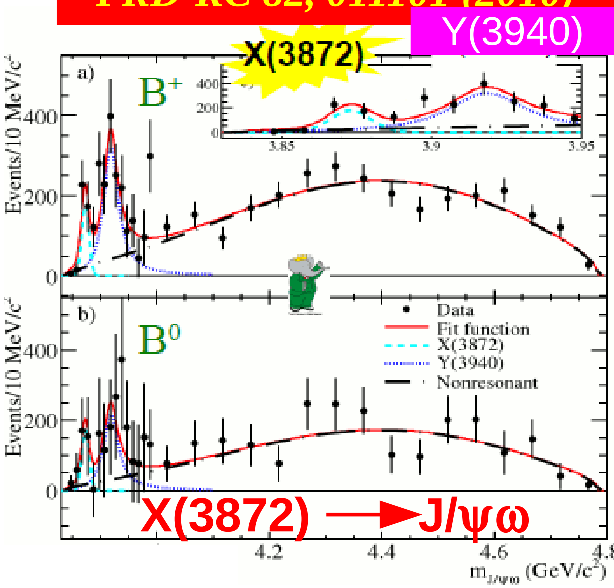


PRD 77, 011102 (2008)



PRD-RC 82, 011101 (2010)

Y(3940)



new

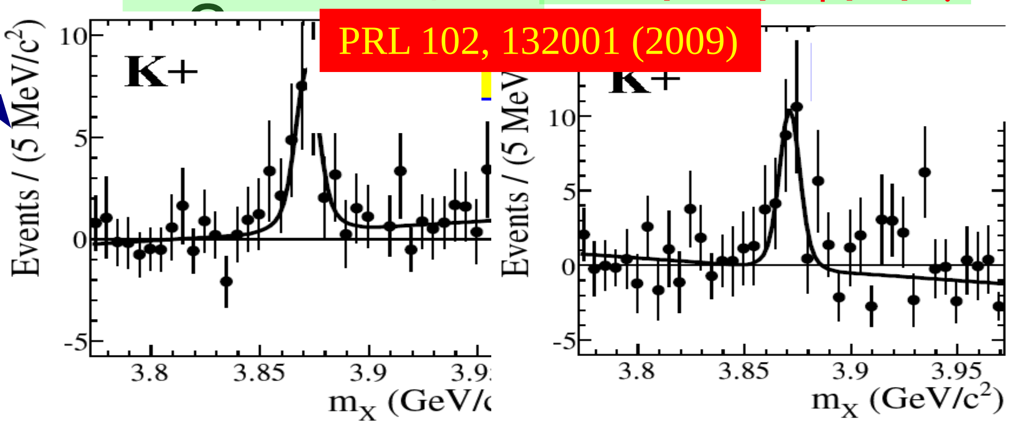
X(3872)

what else?

X(3872) → J/ψ γ

X(3872)→ψ(2S) γ

PRL 102, 132001 (2009)



- X(3872) is seen now in several B decay modes
- Y(3940) is seen in J/ψω from B decays

Summary of the main results: $B \to Z\ K$

- Belle has reported a new charged charmonium-like state in the decay: $B \to Z^- K$, $Z^- \to \psi(2S)\pi^-$ (PRL *100, 142001 (2008)*)

- The reported mass and width are:

  $M = (4443^{+15}_{-12}\ {}^{+17}_{-13})$ MeV/c^2
  $\Gamma = (109^{+86}_{-43}\ {}^{+57}_{-52})$ MeV

  6.5σ

PRD 80, *031104 (2009)*

- BaBar searched for the Z(4430)$^-$ in the decay modes $B^{-0} \to \psi\pi^- K^{0+}$

- Describe the $K\pi^-$ system in detail, since structure in the $K\pi^-$ mass and angular distributions dominates each Dalitz plot. PRD 79, 112001 (2009)

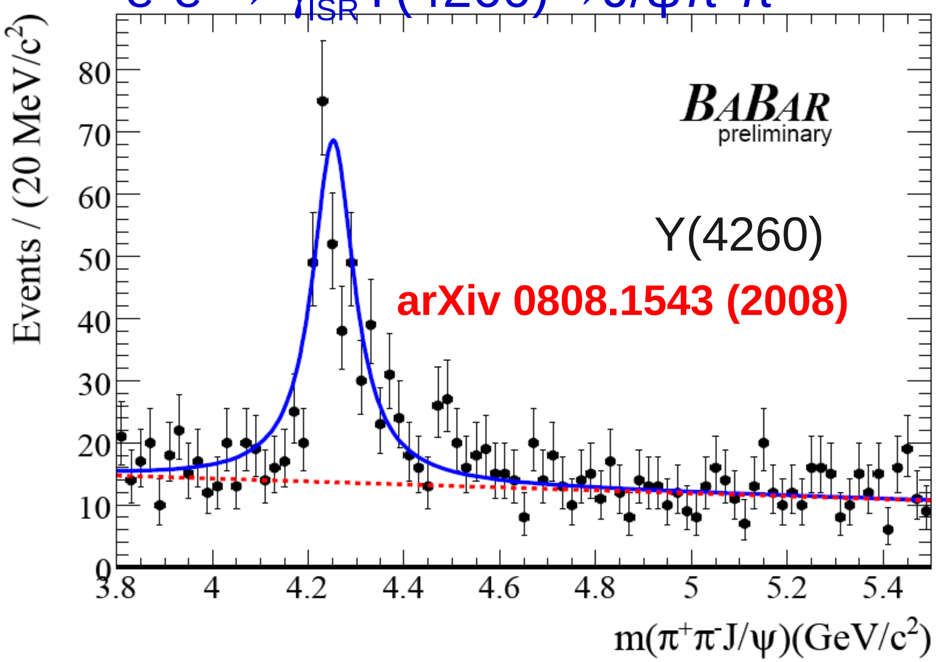
- Correct the data for efficiency event-by-event across the Dalitz plot, and describe using only S-, P-, and D-wave intensity contributions

- Project each $K\pi^-$ description onto the relevant $\psi\pi^-$ mass distribution to investigate the need for Z(4430)$^-$ signal above this "$K\pi^-$ background"

No significant effect of any Z-(4430) was found!

Summary of the main results: $e^+e^- \to \gamma_{ISR} Y$

$e^+e^- \to \gamma_{ISR} Y(4260) \to J/\psi \pi^+\pi^-$



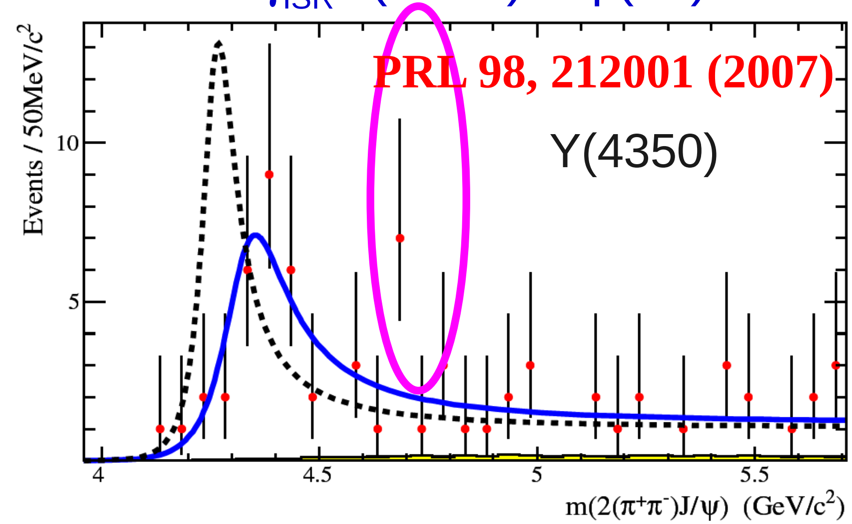
BABAR update on Y(4260) (preliminary):

$m = 4252 \pm 6(\text{stat})\ ^{+2}_{-3}\ (\text{syst})\ \text{MeV}/c^2$

$\Gamma_Y = 105 \pm 18(\text{stat})\ ^{+4}_{-6}\ (\text{syst})\ \text{MeV}$

No evidence for enhancement at ~4050 MeV/c^2 reported by Belle (*PRL 99, 182004 (2007)*)

$e^+e^- \to \gamma_{ISR} Y(4350) \to \psi(2s)\pi^+\pi^-$



Y(4350) has been confirmed by Belle (PRL 99, 142002 (2007))

Belle reports another state:
m=4660±12 MeV/c^2, Γ=48±15 MeV

PRD-RC 82, 011101 (2010)

Evidence of X(3872)→ J/ψ ω

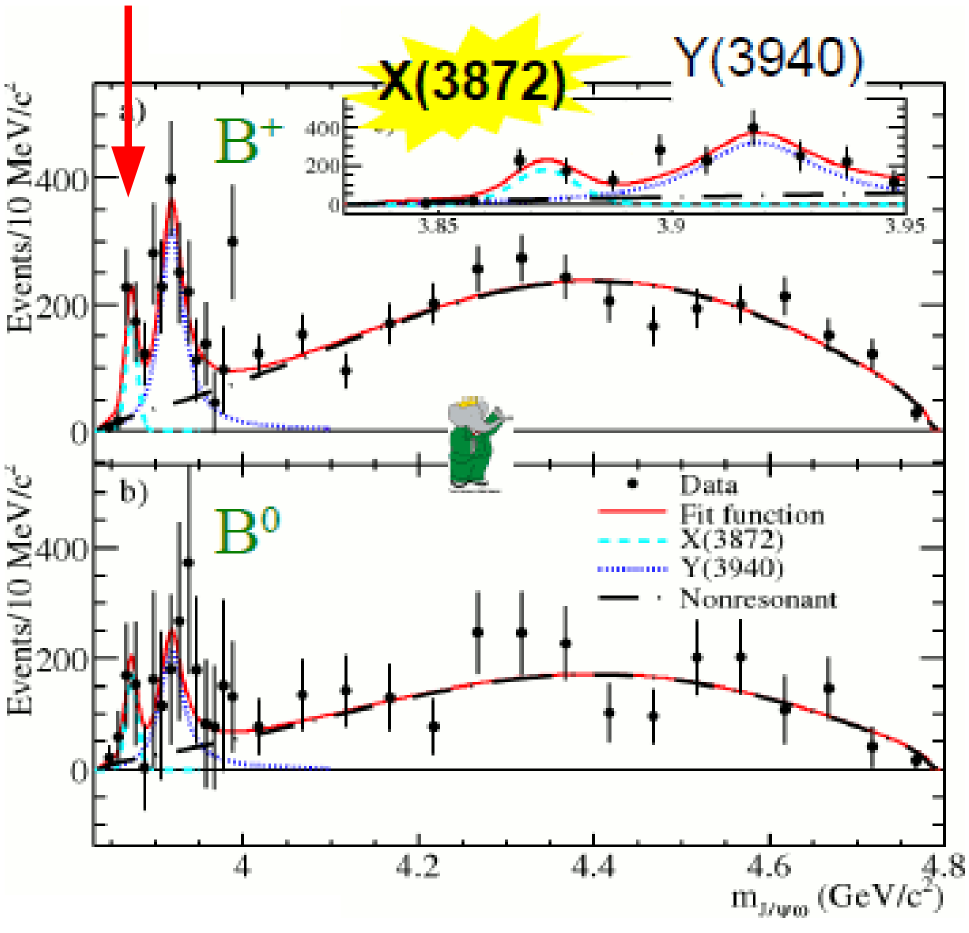
- Belle reported an excess of events in m(3π) above 750 MeV/c^2 in the decay B→J/ψ3πK

  $|m_{J/\psi 3\pi}-3872|<16.5$ MeV/c^2

  ⇒ interpreted as X→J/ψω

- *BABAR* confirmed the existence of the Y(3940) in B→Y(J/ψω)K but could not see the X(3872)→J/ψωK signal when requiring PRL 101, 082001 (2008)

  0.7695< m3π<0.7965 *(B+)*



New analysis: 4.0σ (X→J/ψω)

Criterion (GeV/c2)	
0.7695<m3π<0.7965 (B+)	*Old analysis*
0.7605<m3π<0.8055 (B0)	
0.7400<m3π<0.7965 (B+)	*New analysis*
0.7400<m3π<0.8055 (B0)	

X(3872) : Gaussian function (resolution)

Y(3940): Breit-Wigner function for the x phase space

Nonresonant: phase-space × Gaussian function × mJ/ψω

Fit Parameter	Value
m_X (GeV/c2)	$3873.0_{-1.6}^{+1.8}$(stat)±1.3(syst)
m_Y (GeV/c2)	$3919.1_{-3.4}^{+3.8}$(stat)±2.0(syst)
Γ_Y (MeV)	31_{-8}^{+10}(stat) ±5(syst)
NX_{Bch} (NX_{B0})	21±7 (6±3(stat))
NY_{Bch} (NY_{B0})	108_{-23}^{+25}(stat) (19±8(stat))
$R(X) = BR(X_{B0})/BR(X_{Bch})$	$1.0_{-0.6}^{+0.8}$(stat)$_{-0.2}^{+0.1}$(syst)
$R(Y) = BR(Y_{B0})/BR(Y_{Bch})$	$0.7_{-0.3}^{+0.4}$(stat) ±0.1(syst)

$$BR = \frac{BF(X \to J/\psi\,\omega)}{BF(X \to J/\psi\,\pi\,\pi)} = 0.7 \pm 0.3\,(B^+)$$

$$BR = \frac{BF(X \to J/\psi\,\omega)}{BF(X \to J/\psi\,\pi\,\pi)} = 1.7 \pm 1.3\,(B^0)$$

***BABAR average*: 0.8 ± 0.3**

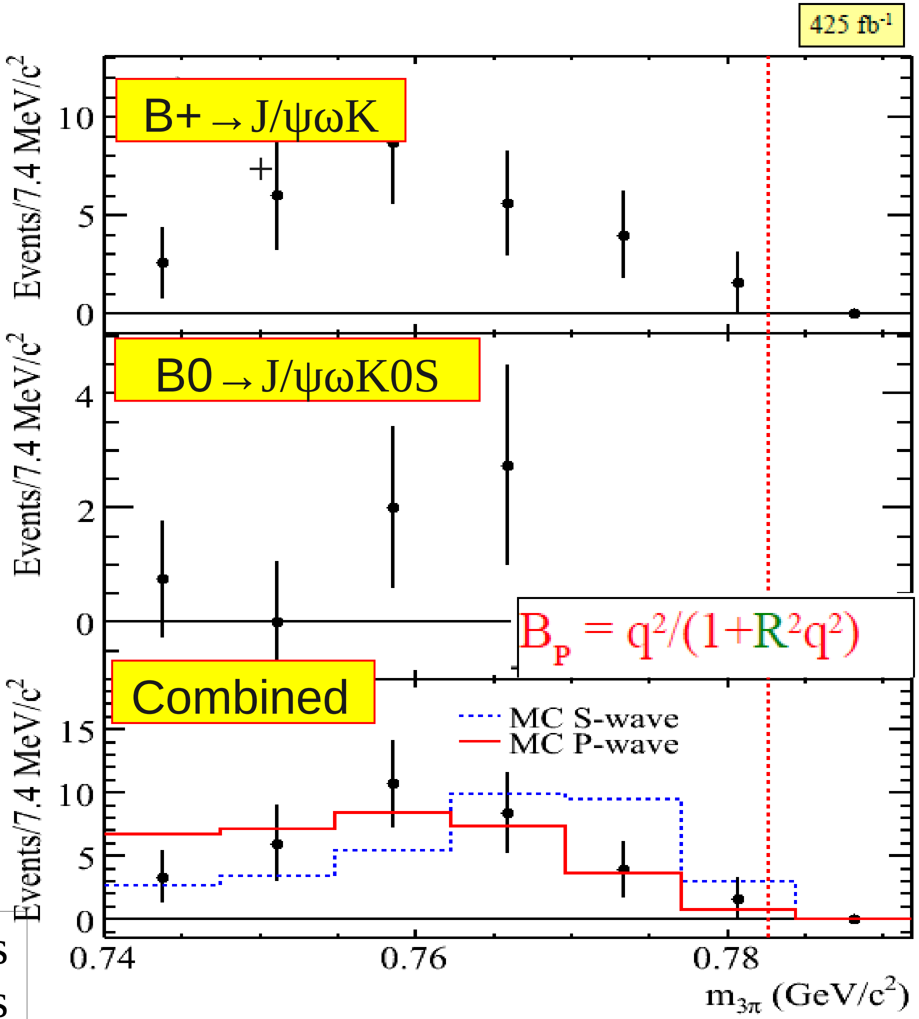
PRD-RC 82, 011101 (2010)

Angular distribution study in J/ψ ω

- The *P-wave* hypothesis for the X(3872) describes data better than S-wave
  - X(3872) is more likely J^P=2- than J^P=1+ state, consistent with charmonium η_{c2}(1D) interpretation.

S-wave: χ2/NDF=10.17/5
P(χ2/NDF)=7%
P-wave: χ2/NDF=3.53/5
P(χ2/NDF)=62%
JP=1+ is still not excluded!

- From the decay modes: X→J/ψγ, X→ψ(2S)γ ⇒ C=+1



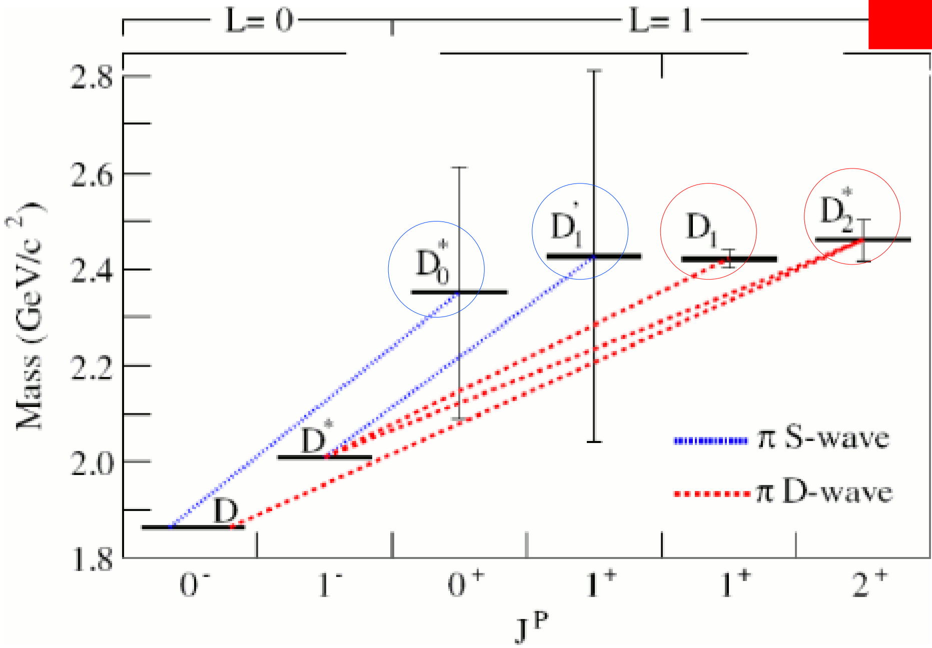
Dalitz weighting technique: each event is given weight of (5/2)(1-3cos2θ_h), where θ_h is the angle between the π+ and π0 in the π+π- rest frame → See SLIDES 40,41,42, 46 for details

Observation of new D states (I)

arXiv:1009.2076

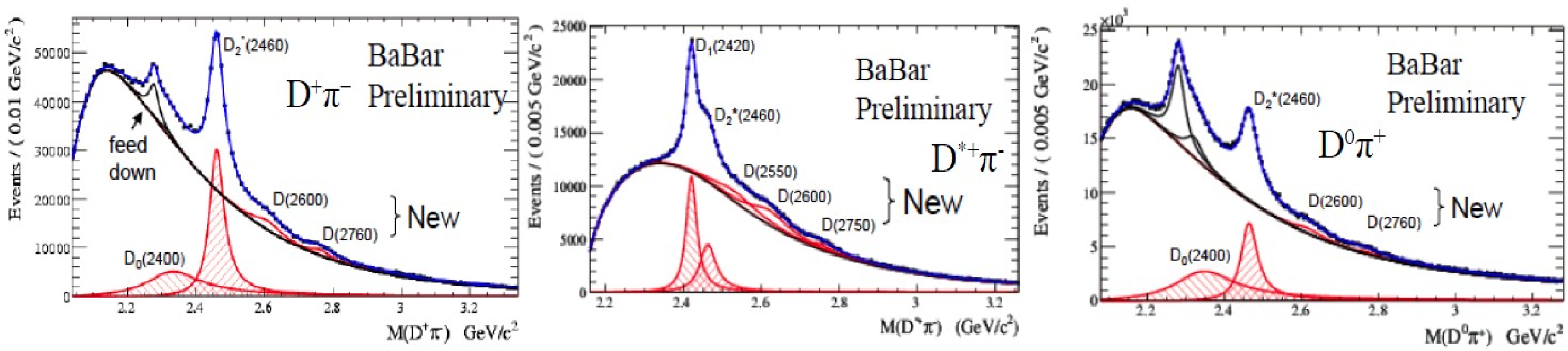
454 fb^{-1}

- 4 new states observed: L=1
  2 in D-waves, Γ ~40 MeV
  2 in S-waves, Γ~300 MeV



- Channel under study:

  $e^+e^- \rightarrow c\bar{c} \rightarrow D^{**}X \rightarrow D^{(*)}\pi X$

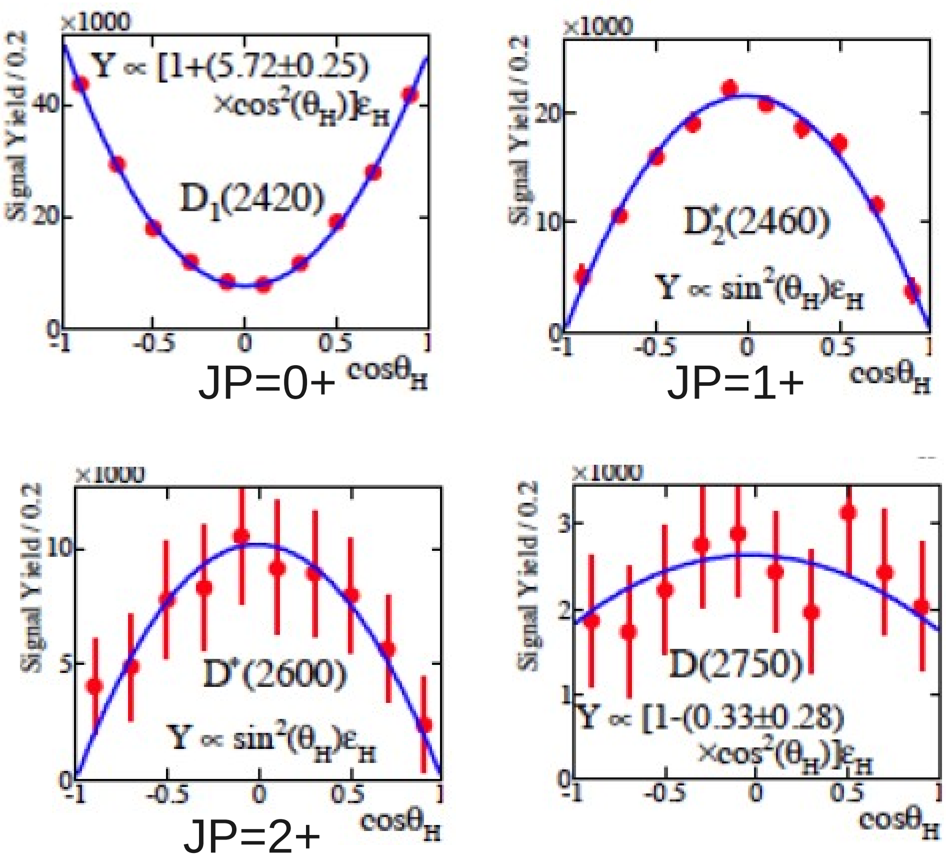


Observation of new D states (II)

arXiv:1009.2076

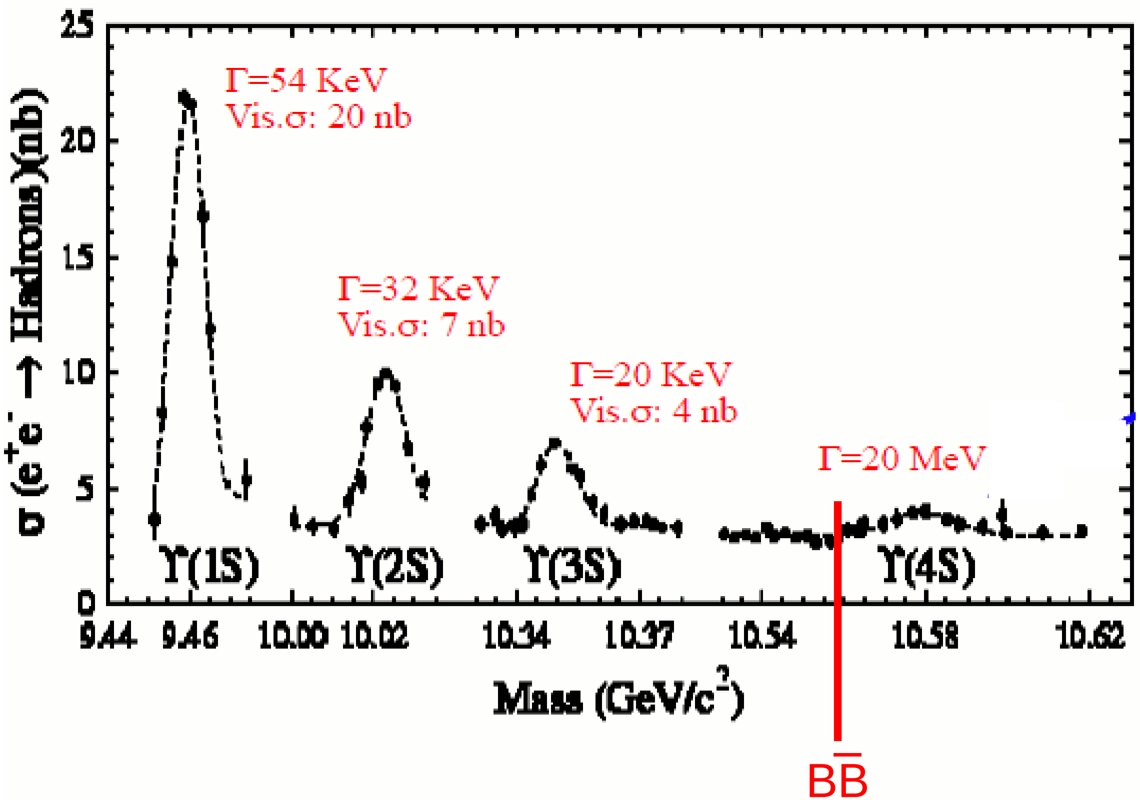
454 fb^{-1}

- precise measurements of mass, width
- possibility to determinate J^P



Bottomonium at B factories

Copious production of 1^{--} in e^+e^- annihilations when $\sqrt{s} = M(\Upsilon)$



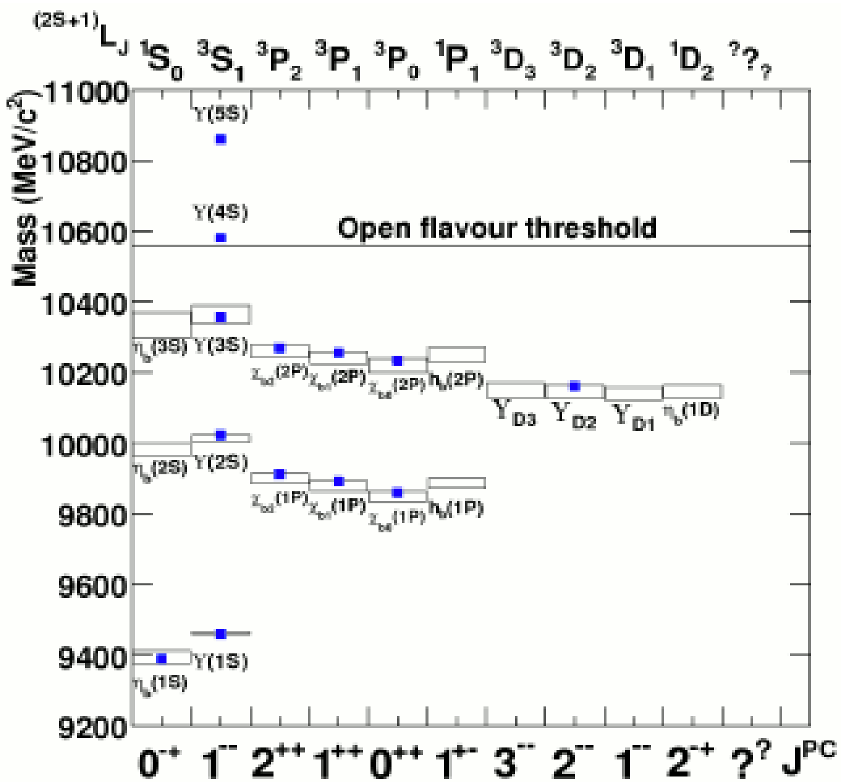
Initial State Radiation (ISR) yields large samples also when running at the $\Upsilon(4S)$

few M events for "free" while running at the $\Upsilon(4S)$

can be used to study $\Upsilon(nS)$ in fully reconstructed final states

inclusive searches or final states with missing particles require on-peak running

Bottomonium production



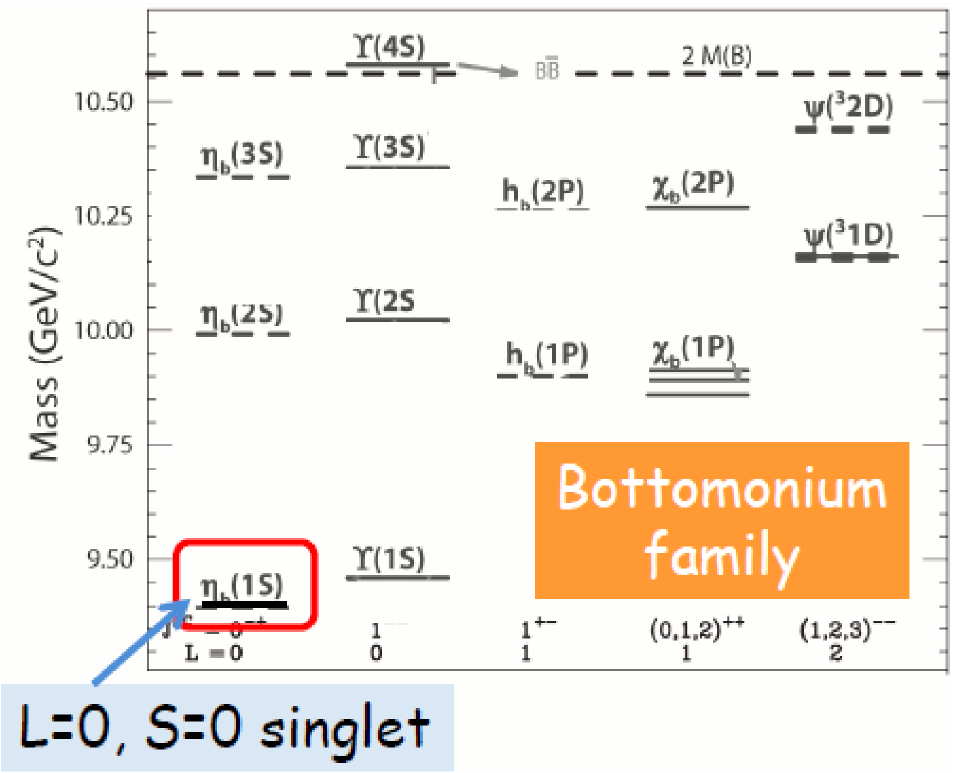
	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
[BaBar logo]	[19+5] M	100 M	120 M
[Belle logo]	100 M	175 M	11 M
[CLEO logo]	20 M	9 M	6 M

Υ(1S) not collected at BaBar
Use di-pion tag to study Υ(1S) decays

- Most data collected at Υ(4S) – decays to $B\bar{B}$ dominate
- Lower narrow resonances produced by ISR
- Dedicated running periods at the narrow Υ(nS) resonances
- 4 fb^{-1} scan above Υ(4S) (BaBar)
- coarse scan above Υ(4S) and large data sample at Υ(5S) (Belle)

Bottomonium states

- η_b and h_b: hyperfine mass splitting
- η_b found by BaBar (2008)
- Bottomonium states with L=0,1 and S=1 are known since 1970s and 1980s
- Search for η_b using $\gamma \rightarrow e^+e^-$ conversions (L = 0 singlet). Also uses Y(2s) samples.
- h_b(1P) not yet observed
- $1D_{J=2}$ state seen by CLEO (2004)
- Spectrum below open-flavour threshold richer than charmonium
- Masses and BFs are important to test potential model and lattice QCD

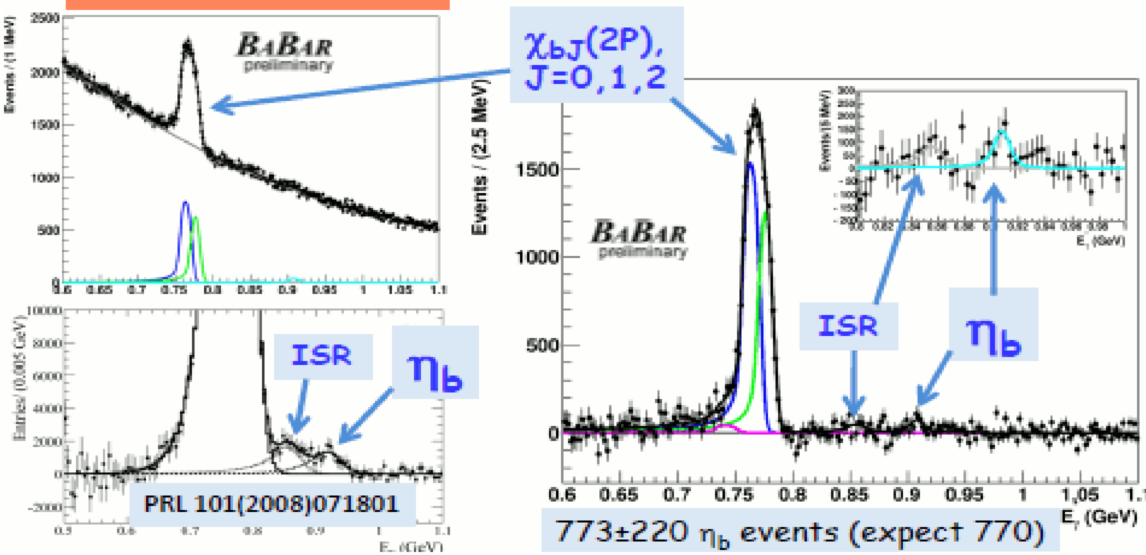


World average mass: η_b = (9390.9±2.8) MeV/c^2

PRL 101 071801 (2008)

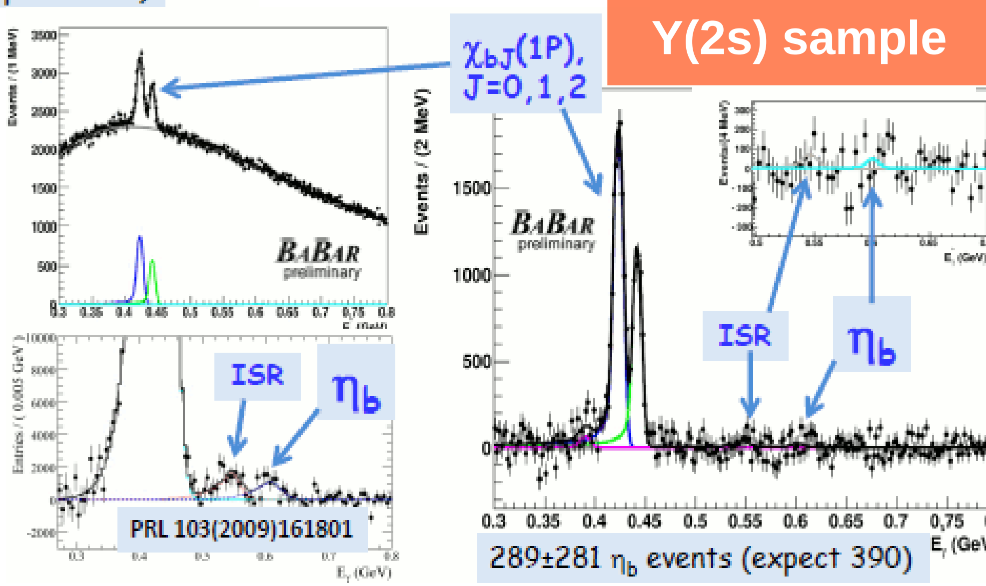
η_b search using $\gamma \rightarrow e^+e^-$ conversion

Y(3s) sample



- η_b discovered in γ recoil spectrum
- It is confirmed by BaBar in Y(2s) (2009)
- It is confirmed by CLEO in Y(3s) (2010)

Y(2s) sample

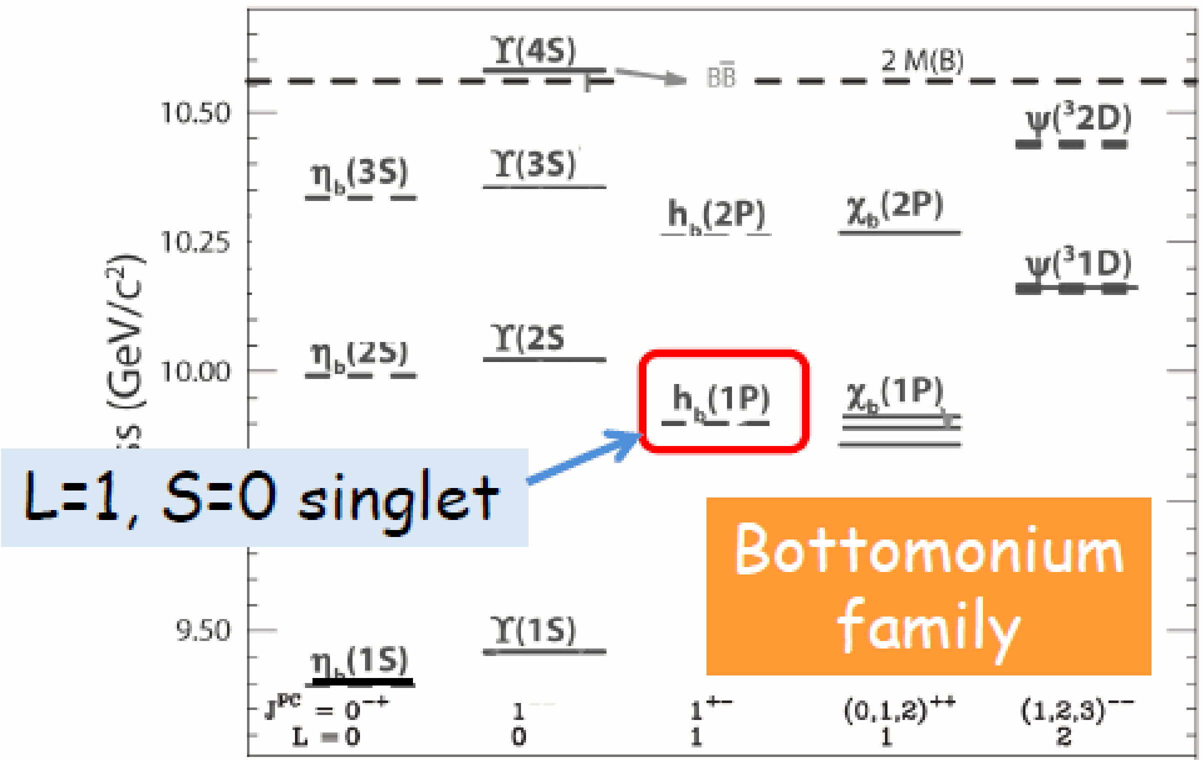


New study in BaBaR:

Y(2s) and Y(3s) to $\gamma\eta_b$, using $\gamma \rightarrow e+e-$

PRELIMINARY results shown at ICHEP10

Bottomonium: search for $h_b(1P)$



- Search for $h_b(1P)$ state (singlet L=1)

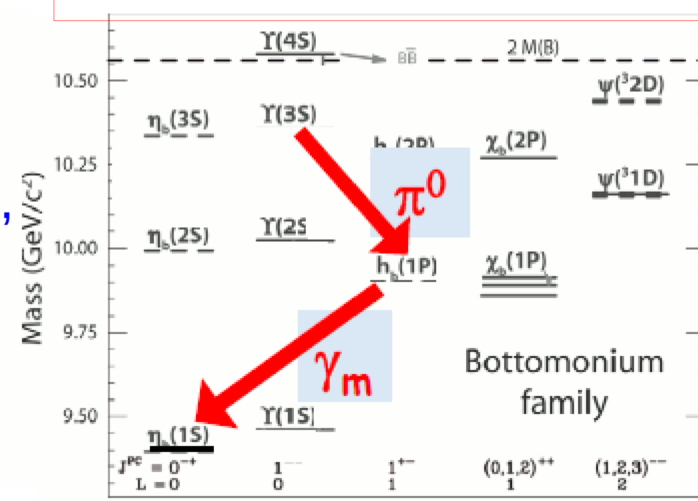
- $\Upsilon(3S) \to \gamma h_b$ forbidden (C-parity)
- Favored production mechanisms

$B[\Upsilon(3S) \to \pi^0 h_b] \sim 4\times10^{-4}$ [Voloshin]

$B[\Upsilon(3S) \to \pi^+\pi^- h_b] \sim 10^{-5}$ [Voloshin]

$\sim 10^{-3}$-10^{-4} [KTY]

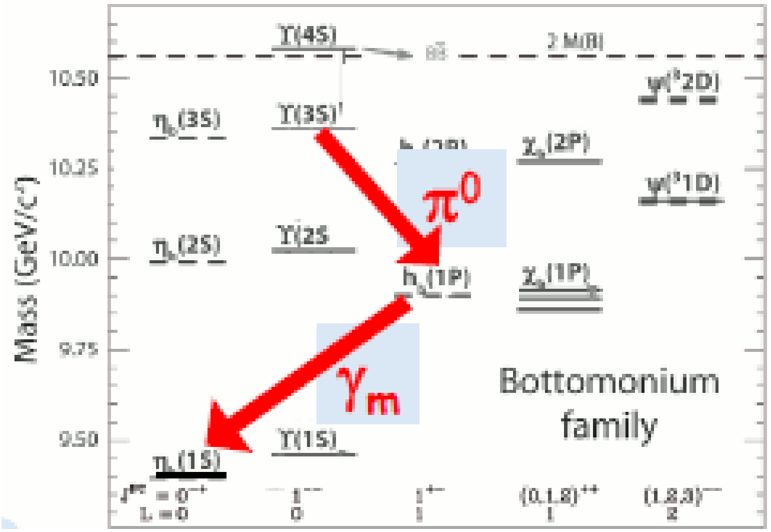
Voloshin, Sov. J. Nucl. Phys. 43 (1986) 1210
Kuang, Tuan & Yan, PR D37 (1988) 1210



- Expected in the decays: $h_b \to \gamma\eta_b$(~41%), ggg(57%), γgg(2%)

Theoretical predictions:
PRD 66, 014012 (2006)

Search for $\Upsilon(3s) \rightarrow \pi^0 h_b(1P)$



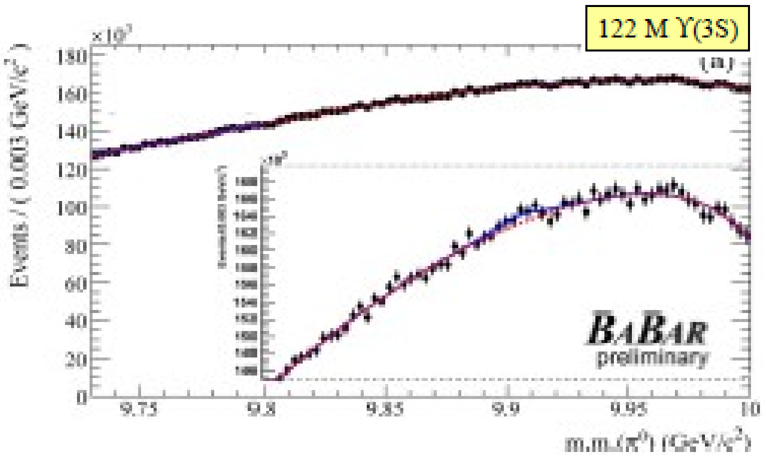
- h_b mass and yield free

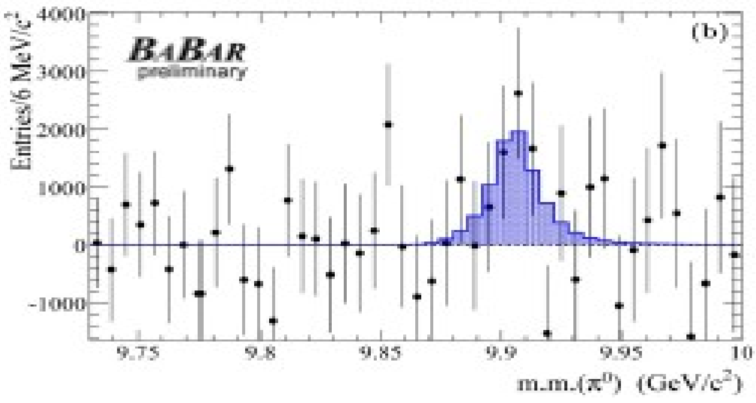
  → 8682 ± 2981 signal events

  ~3σ (stat.), 2.7σ (stat.+syst.)

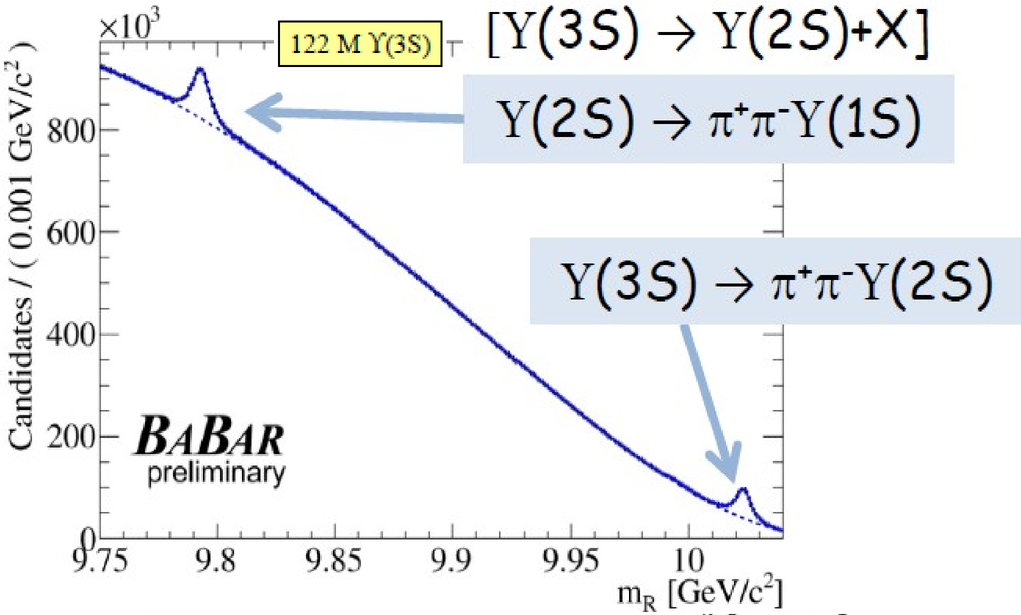
- Fitted mass: 9903±4 MeV agrees with expectation (9900)

$$M_{recoil} \equiv \sqrt{(E^*_{\Upsilon(3S)} - E^*_{\pi^0})^2 - (\vec{p}^*_{\pi^0})^2}$$



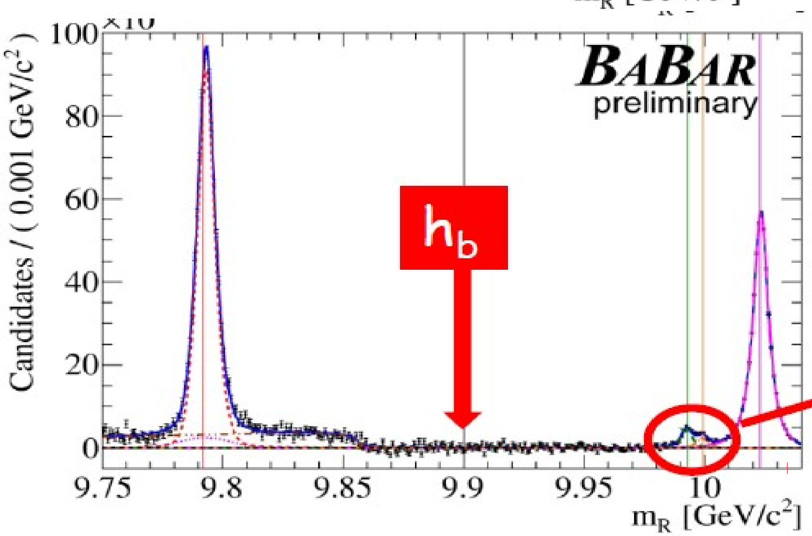


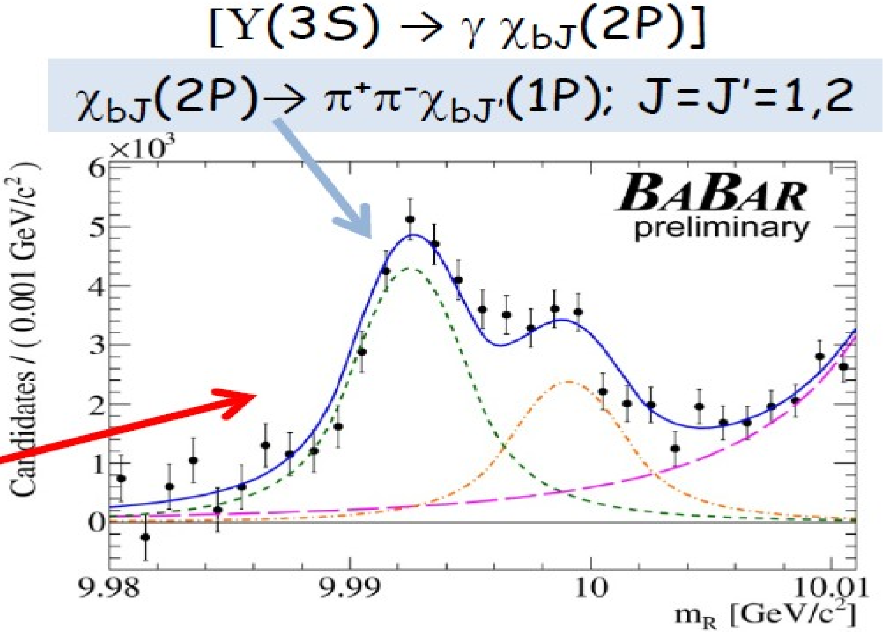
Search for $\Upsilon(3s) \to \pi^+\pi^- h_b(1P)$



χ^2 fit→ Fitted signal yield (m_{hb}=9900 MeV):

-1106±2432 events





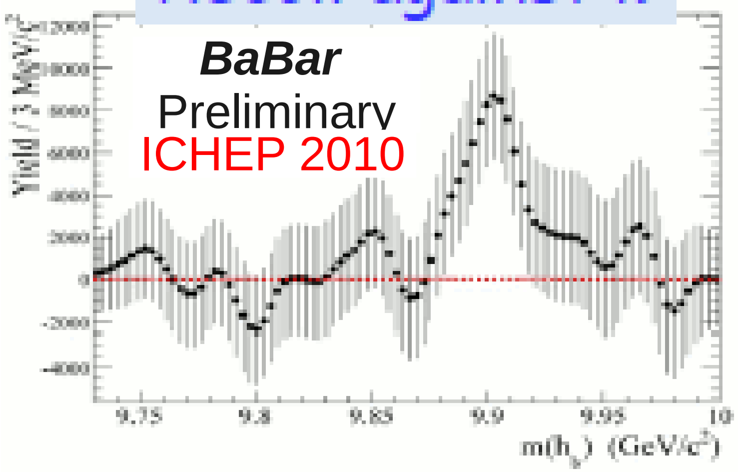
h_b mass scan

No indication of a signal in the $Y(3s)\to\pi^+\pi^- h_b$ channel is seen

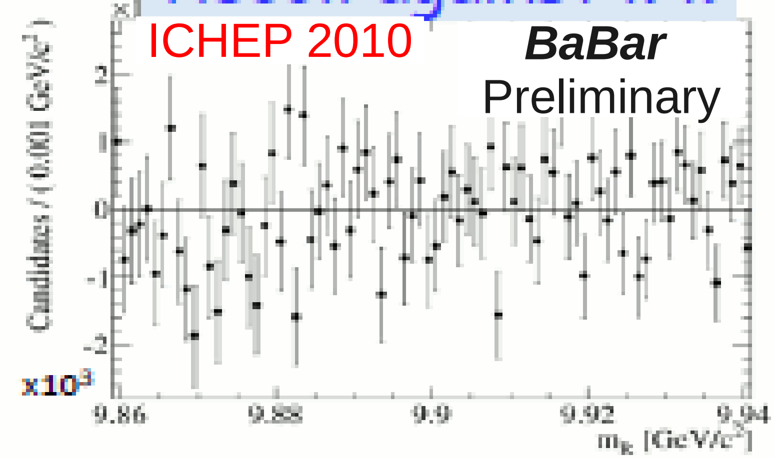
$B[Y(3S) \to \pi^+\pi^- h_b] < 1.0\times10^{-4}$ at 90% CL for m_{hb} = 9.9 GeV

[CLEO 1994: $< 1.8\times10^{-3}$ for m_{hb}=9.9 GeV]

Recoil against π^0



Recoil against $\pi^+\pi^-$



→ Predictions for ratio $B[Y(3S) \to \pi^0 h_b] / B[Y(3S) \to \pi^+\pi^- h_b]$:

~ 20 [Voloshin] ; ~ 1/20 [Kuang et al.]

→ data more consistent with Voloshin

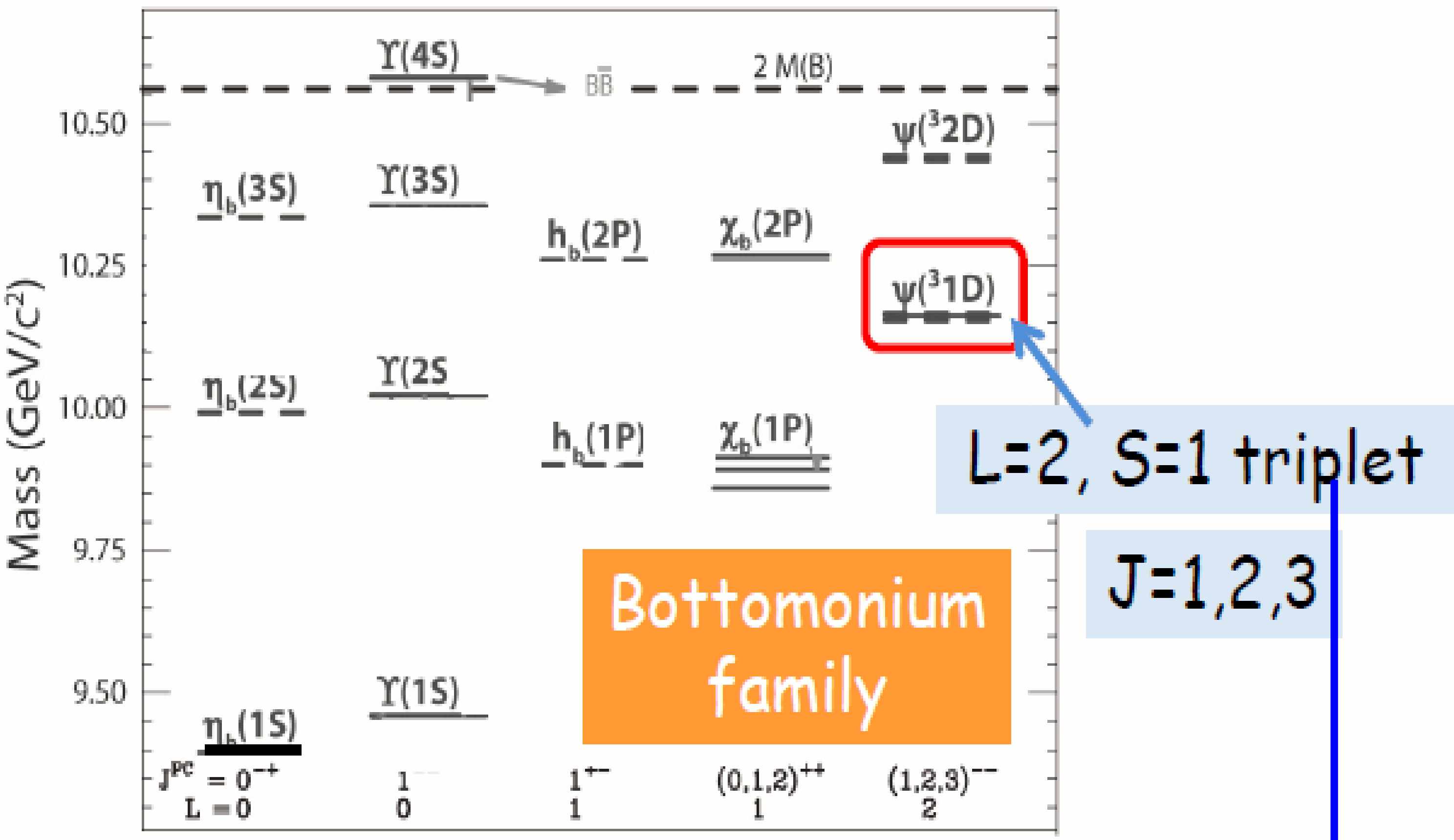
Bottomonium search for L = 2

- Observation of $1D_{J=2}$ state (triplet L=2)

- Predicted mass: ~10160±10 MeV/c^2

Godfrey&Rosner (2001) 097501

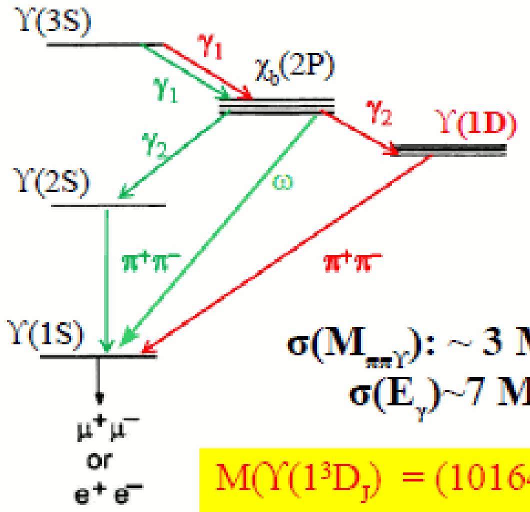
- Predicted separation between triplet states: ~5-12 MeV/c^2

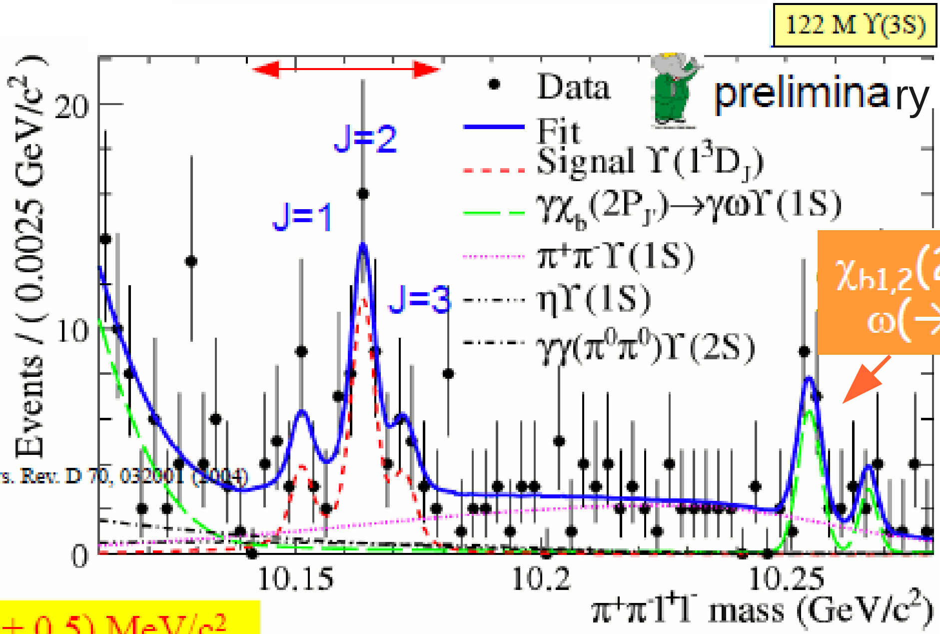


$\Upsilon(1^3D_J) \rightarrow \pi^+\pi^-\Upsilon(1s)$

arXiV:1004.0175

Complete reconstruction of the event
- 6 different cascades for Y(1D)
- several other cascades with the same final state





$\sigma(M_{\pi\pi\Upsilon})$: ~ 3 MeV/c²
$\sigma(E_\gamma)$~7 MeV

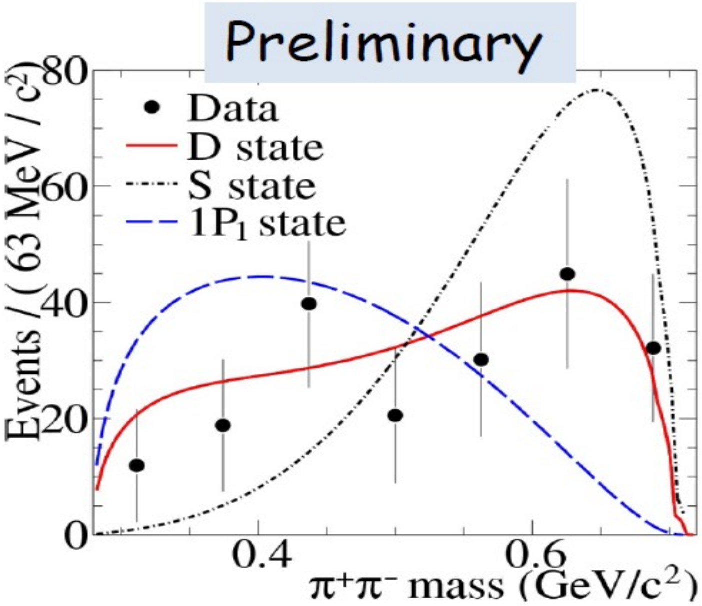
$M(\Upsilon(1^3D_J)) = (10164.5 \pm 0.8 \pm 0.5)$ MeV/c²

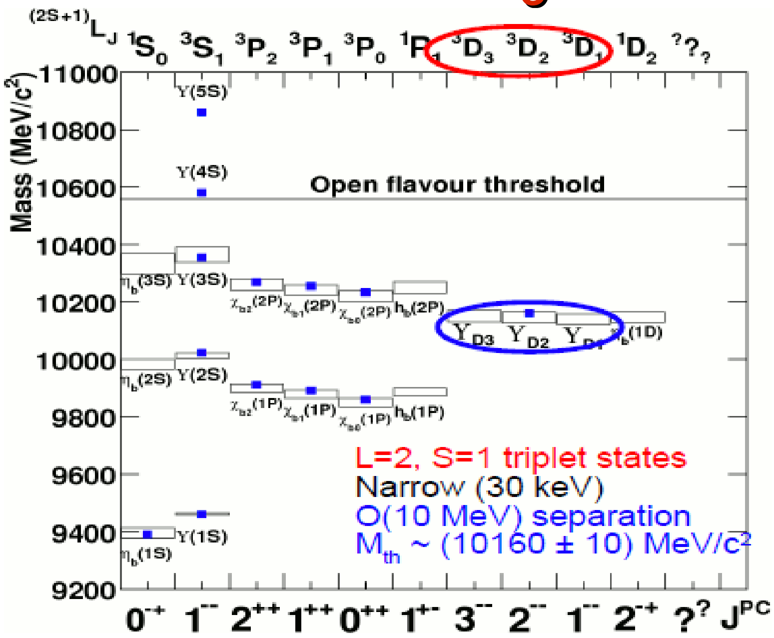
CLEO: $M = (10161.1 \pm 0.6 \pm 1.6)$ MeV/c² $\Upsilon(3S)\rightarrow\gamma\gamma[\gamma\gamma\Upsilon(1S)]$ PRD 70, 032001 (2004)

1^3D_J	Event yields	Sign.	Branching fraction	90% CL UL	Kwang & Yan (1981)	Ko (1993)	Moxhay (1988)
J=1	$10.6\,^{+5.7}_{-4.9}$	1.8 σ	$(0.42\,^{+0.27}_{-0.23} \pm 0.10)\%$	< 0.82%	40%	1.6%	0.20%
J=2	$33.9\,^{+8.2}_{-7.5}$	5.8 σ	$(0.66\,^{+0.15}_{-0.14} \pm 0.06)\%$		46%	2.0%	0.25%
J=3	$9.4\,^{+6.2}_{-5.2}$	1.7 σ	$(0.29\,^{+0.22}_{-0.18} \pm 0.06)\%$	< 0.62%	49%	2.2%	0.27%
Combined	$53.8\,^{+10.2}_{-9.5}$	6.2 σ					

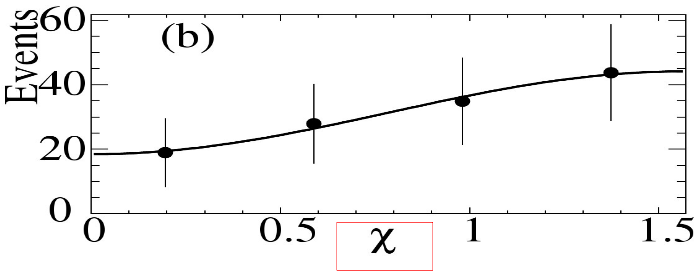
→ First observation of hadronic $\Upsilon(1^3D_J)$ decays

Quantum numbers of $Y(1^3D_J)$





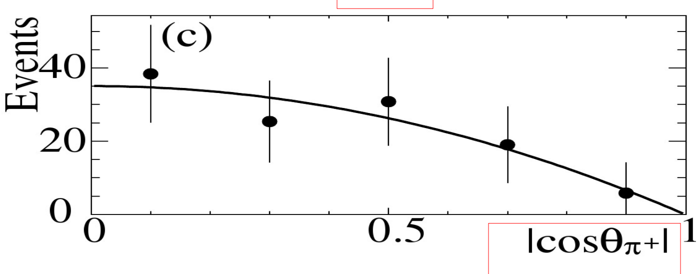
Fit: $\beta = -0.41 \pm 0.29 \pm 0.10$ → consistent with J=2 & P=-1



[if J odd, $dN/d\chi$ would decrease with increasing χ for P=-1]

Sign of β: **sign(β)= $(-1)^{J}P$** P=parity

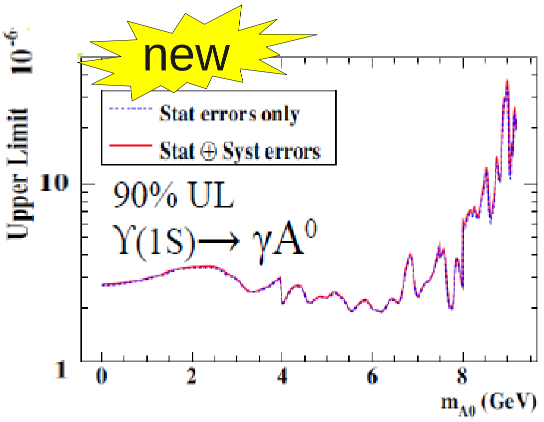
[J.R. Dell'Aquila & C.A. Nelson, PRD33 (1986) 80]

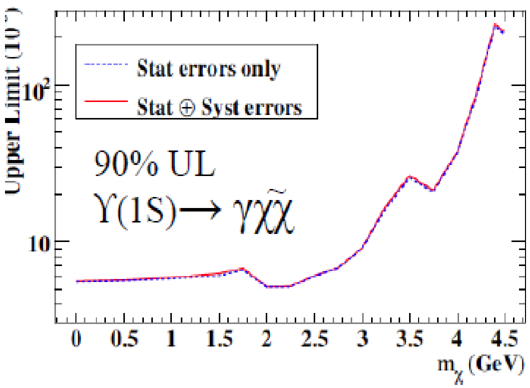


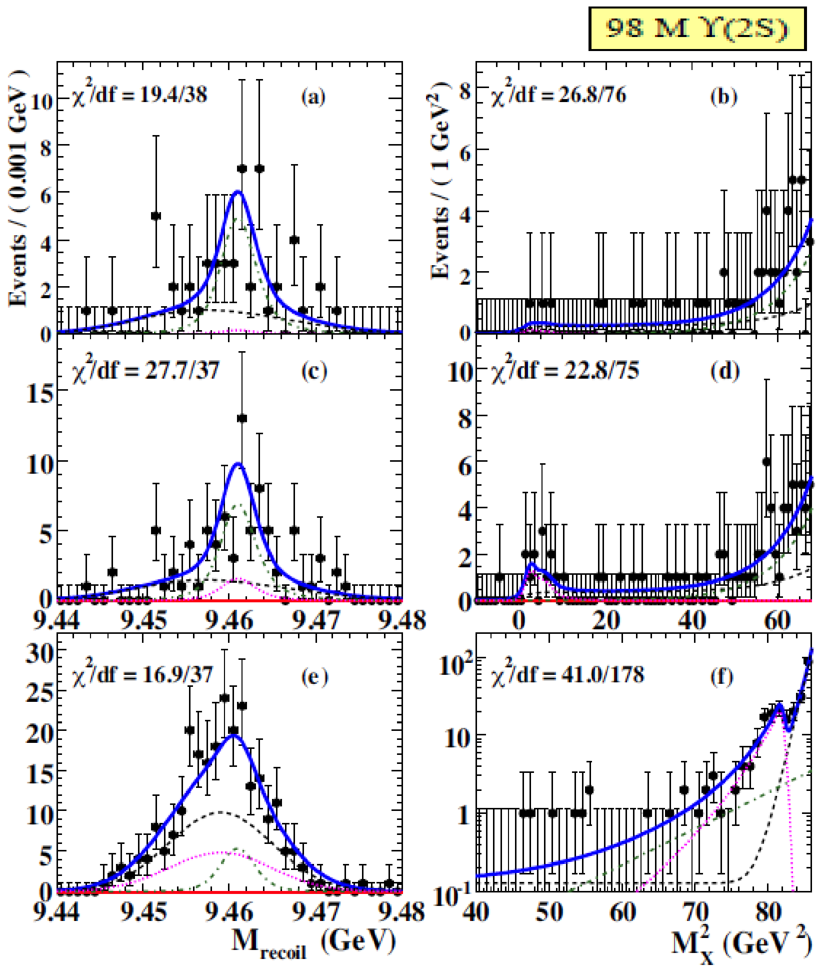
$dN/d\chi \sim 1 + \beta\cos(2\chi)$

arXiV:1007.4646

Υ(1s) → invisible





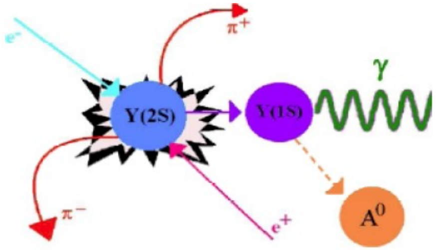


Old search: $B(\Upsilon(3S) \rightarrow \gamma A^0)*B(A^0 \rightarrow inv.) < (0.7\text{-}31)10^{-6}$

$m(A^0) < 7.8$ GeV arXiV:0808.0017

Huge background not negligible due to QED

NEW STRATEGY:



$\Upsilon(2S) \rightarrow \pi^+\pi^-\Upsilon(1S)$

$$M^2_{recoil} = M^2_{\Upsilon(2S)} + m^2_{\pi\pi} - 2M_{\Upsilon(2S)}E^*_{\pi\pi}$$

$$M^2_X = (\mathcal{P}_{e^+e^-} - \mathcal{P}_{\pi\pi} - \mathcal{P}_\gamma)^2$$

Conclusions

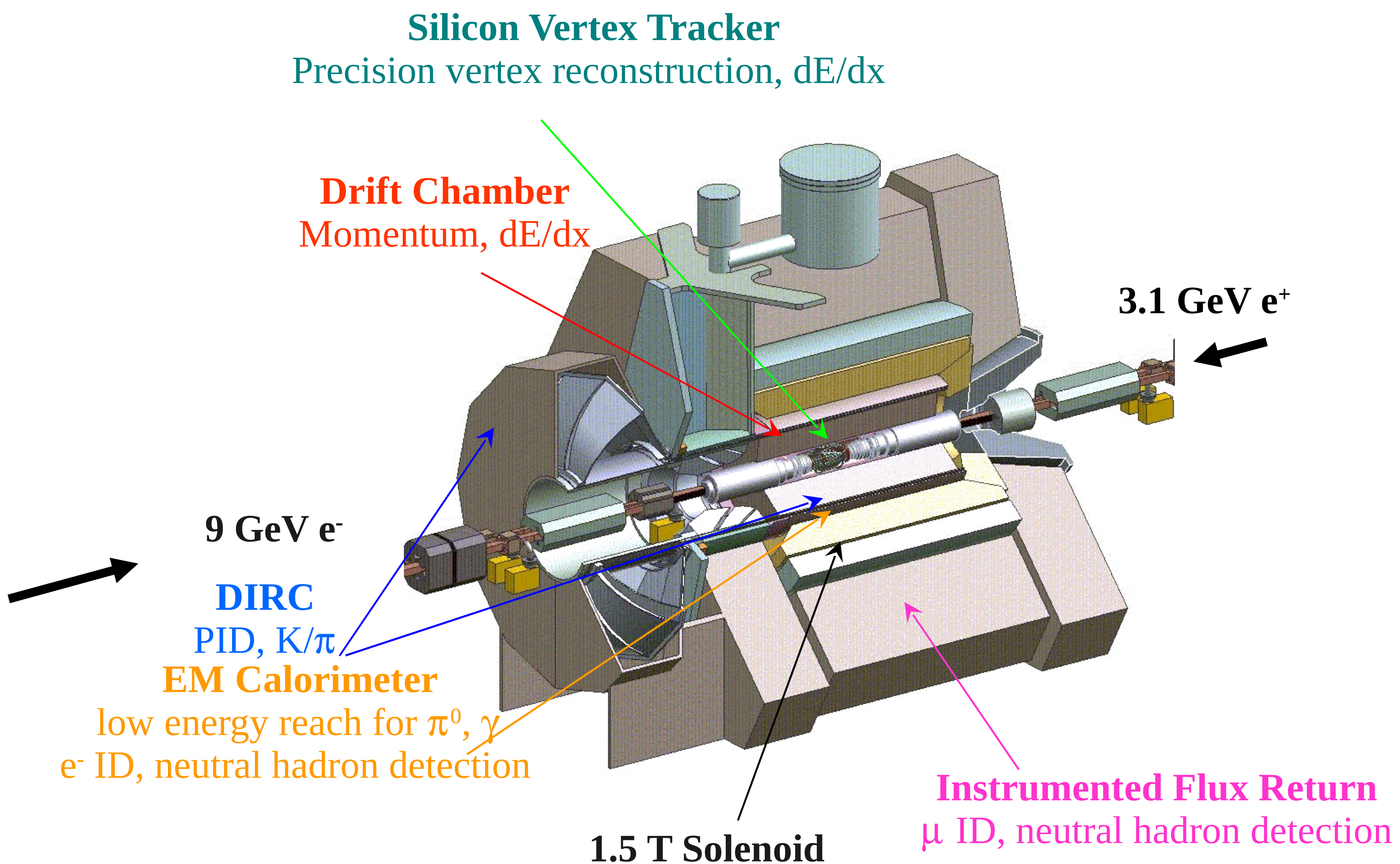
- After 2 years from the day that BaBar stopped to collect data several analysis are still ongoing
- Many results in spectroscopy are coming.....
- BaBar collected the largest world Y(3s) sample
- Converted photons in Y(3s) and Y(2s) to $\gamma\eta_b$, and the η_b mass measurement now is improved
  - h_b (1P) was observed in Y(3s) data to $\pi^0 h_b$
- First observation of Y(1^3D_J) through hadronic decays (6.2σ): first tests for L. P, J are done
- Important confirmation for X(3872)$\rightarrow$J/$\psi\omega$.
- Assignment for JP=2- favored for X(3872): 7%(S-wave) vs 62% (P-wave)

See slide 46

- New observation of D states

Back up slides

The BaBar detector



X(3872)

Belle: PRL 91, 262001 (2003), cited 412

CDF: PRL 91, 262001 (2003) PRL 93, 072001 (2004)

D0: PRL 93, 162002 (2004))

BABAR: PRD 72, 054026(2005)
PRD 73, 014014(2006)

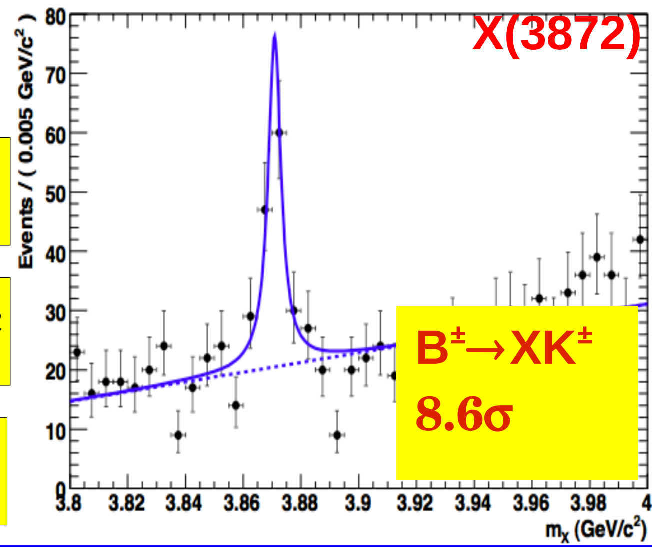
- Final result from BABAR on the study:
  $B \to XK$, $X \to J/\psi\pi^+\pi^-$

[413fb^{-1}] PRD77,111101(2008)

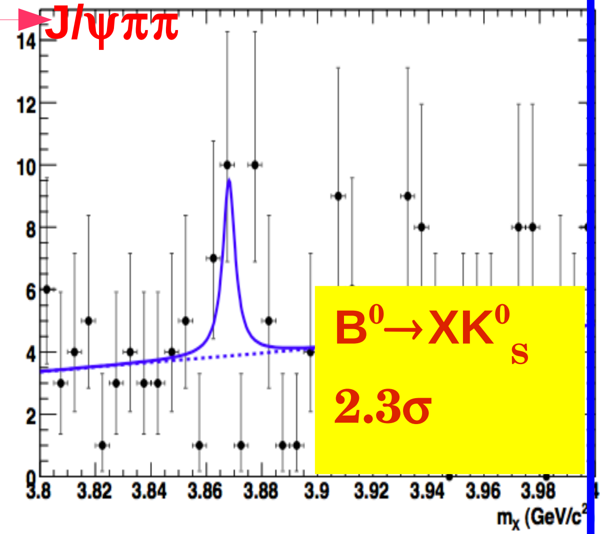
$R(B^0/B^\pm) = 0.41 \pm 0.24 \pm 0.05$

$\Delta M = (2.7 \pm 1.6 \pm 0.4)$ MeV/c^2

$\Gamma < 3.3$ MeV @90%CL



→ J/ψππ



$BF(B^+ \to XK^+, X \to J/\psi\pi^+\pi^-) = (8.4 \pm 1.5 \pm 0.7) \times 10^{-6}$

$BF(B^0 \to XK^0, X \to J/\psi\pi^+\pi^-) = (3.5 \pm 1.9 \pm 0.4) \times 10^{-6}$

$< 6.0 \times 10^{-6}$ @ 90% C.L.

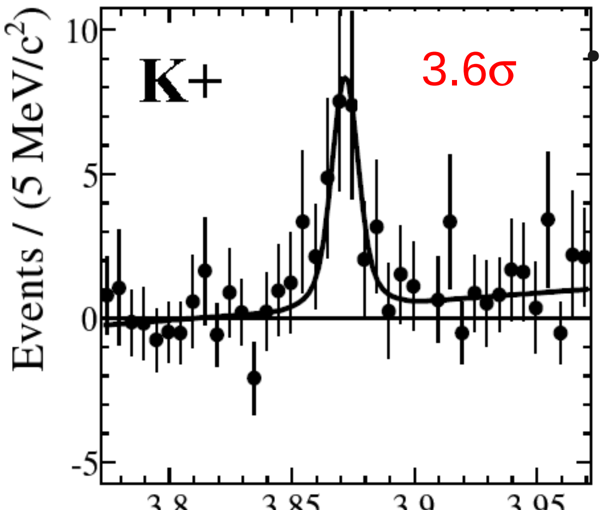
Narrow resonance!

Molecular model predicts $R(B^0/B^\pm) < 0.1$

What is this state?

Final result from BABAR on the analysis:

$B^+ \to X(3872)K^+$, $X(3872) \to J/\psi\ \gamma$



[424 fb^{-1}]

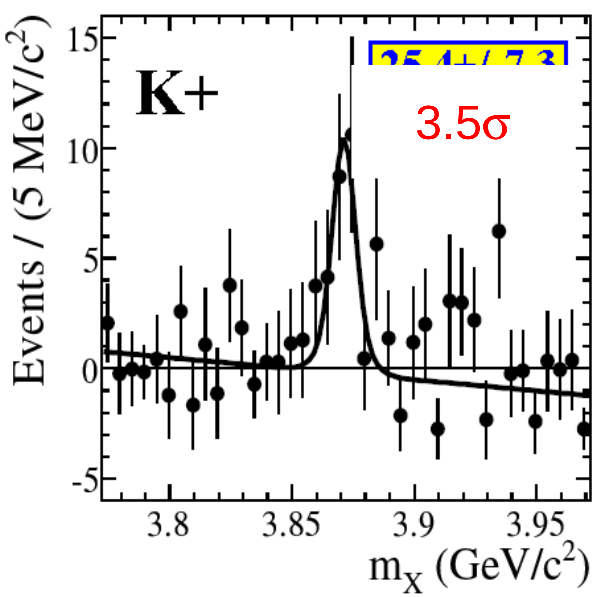
$BF(B^+ \to X(3872)K^+) \times (X(3872) \to J/\psi\gamma) =$
$(2.8 \pm 0.8 \pm 0.2) \times 10^{-6}$

23.0±6.4 events measured

PRD 74, 071101 (2006)
PRL 102, 132001 (2009)

C-parity: 1$^+$

First evidence for $B^+ \to X(3872)K^+$,
$X(3872) \to \psi(2S)\ \gamma$



$BF(B^+ \to X(3872)\ K^+) \times (X(3872) \to \psi(2S)\gamma) =$
$(9.5 \pm\ 2.7 \pm\ 0.9) \times 10^{-6}$

$BF(X(3872) \to \psi(2S)\ \gamma) /\ BF(X(3872) \to J/\psi\gamma =$
3.4 ± 1.4

BaBar:
PRD 77, 011102 (2008)

[347 fb^{-1}]

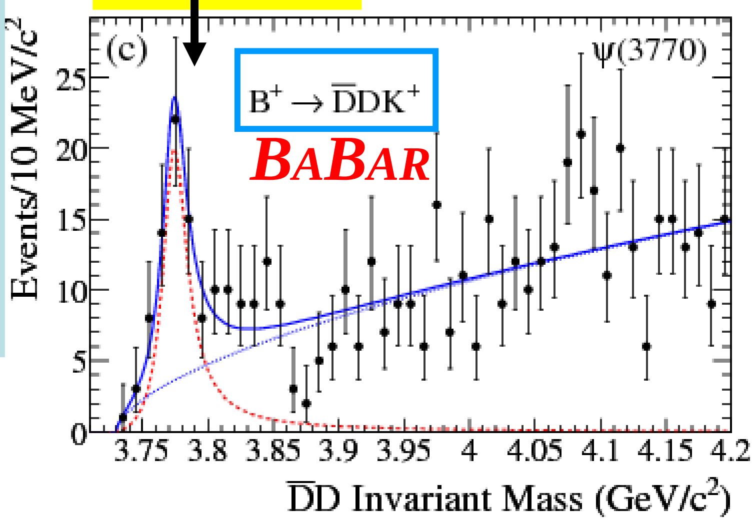
BaBar studied additional 8 channels:

$B^+ \to D^0\bar{D}^{*0}K^+ + D^{*0}\bar{D}^0K^+$
$B^0 \to D^0\bar{D}^{*0}K^0 + D^{*0}\bar{D}^0K^0$

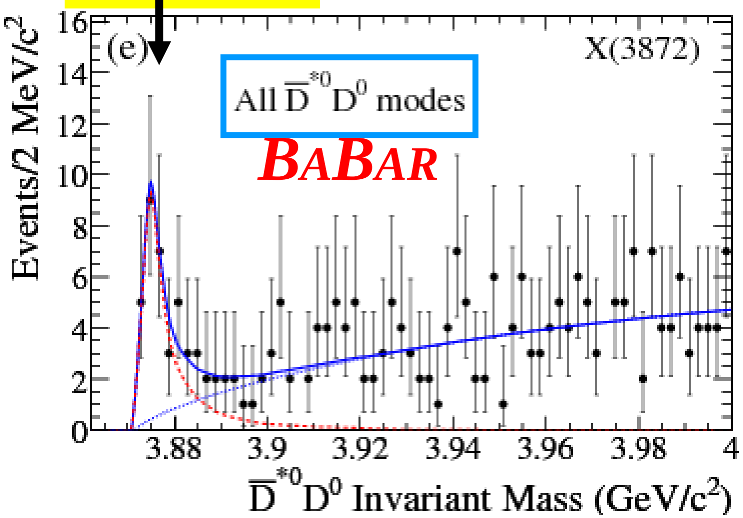
$D^* \to D^0\gamma$ and $D^0\pi$

No $X \to D^0\bar{D}^0$

ψ(3770)



X(3872)



experiment	mass (MeV/c^2)	Branching fraction
BABAR $D^0\pi + D^0\gamma$	**3875.1±1.1±0.5**	$(1.67\pm0.36\pm0.47)\times10^{-4}$ B^+
BELLE Only $D^0\pi$ $D^0\pi + D^0\gamma$	$3875.2^{+0.3}_{-1.6}\pm0.8$ $3872.6^{+0.5}_{-0.4}\pm0.4$	$(1.22\pm0.31^{+0.23}_{-0.30})\times10^{-4}$ B^0+B^+ $(0.73\pm0.17\pm0.08)\times10^{-4}$

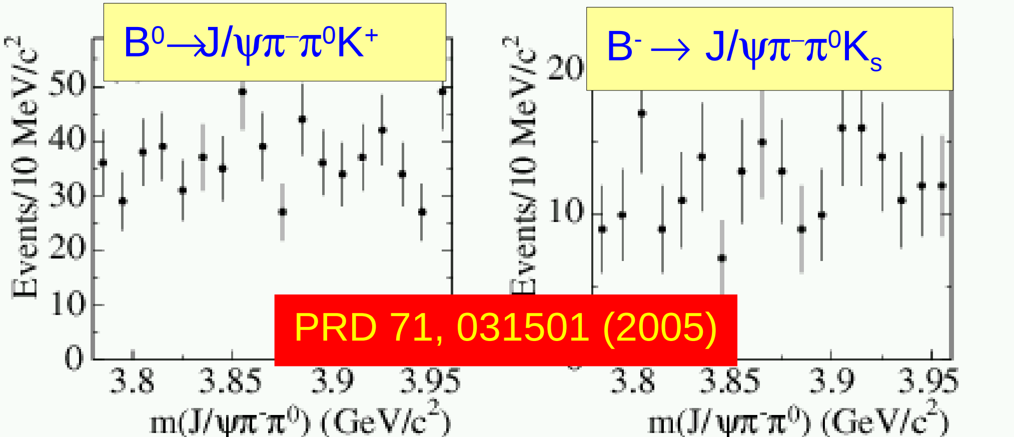
[arXiv:0810.0358]: Belle has recently reported a new mass value.

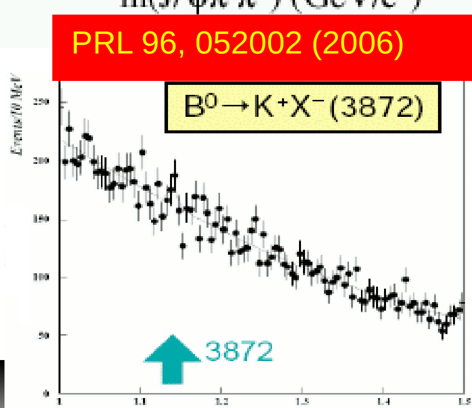
BABAR and Belle disagree on this analysis! → See slides 40 and 41

ππ invariant mass study (X →J/ψππ):

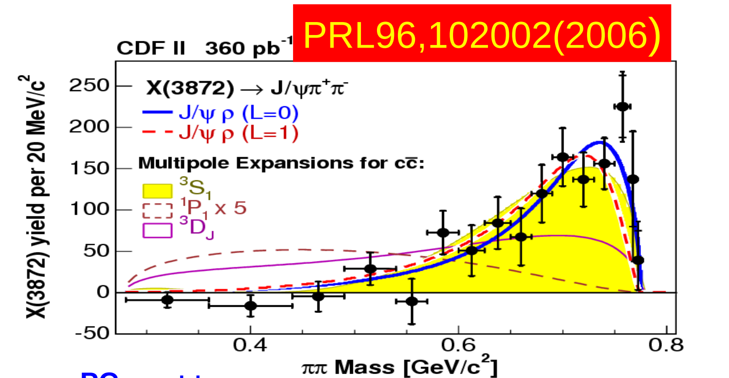
- ππ inv. mass compatible with ρ
  ⇨ I = 1; but:

  forbidden $J/\psi\pi^0\pi^0$, $J/\psi\pi^0$, $J/\psi\eta$
- Decay X(3872)J/ψρ against charmonium hypothesis
- **I=0 favored** for X(3872)→ J/ψππ

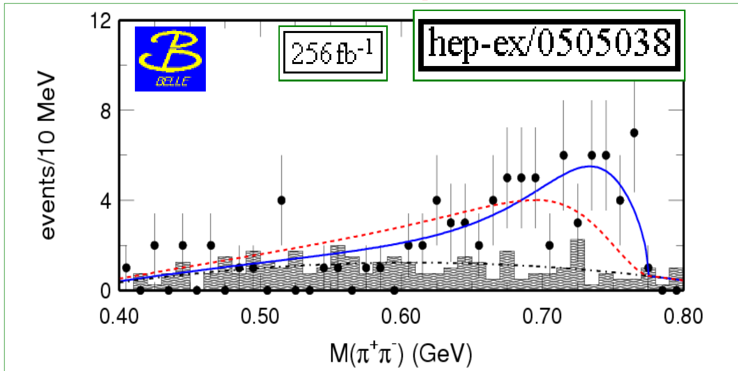




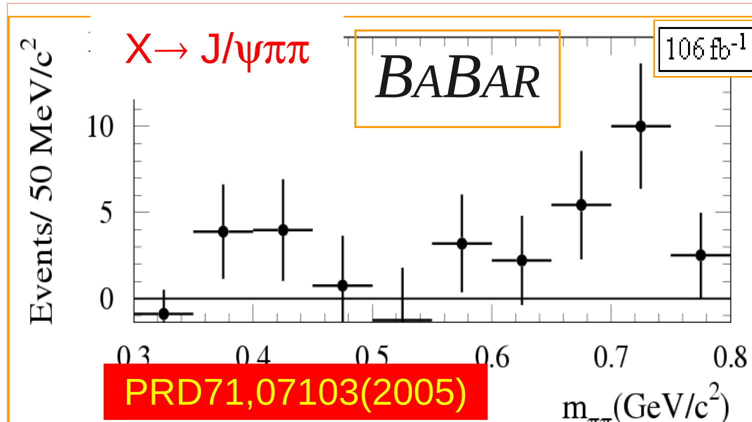
No evidence
of charged partners



★ $J^{PC}=1^{++}$ (S-wave) or
★ $J^{PC}=2^{-+}$ (P-wave, ρ–ω interference)



$J^{PC}=1^{++}$ (S-wave) favored

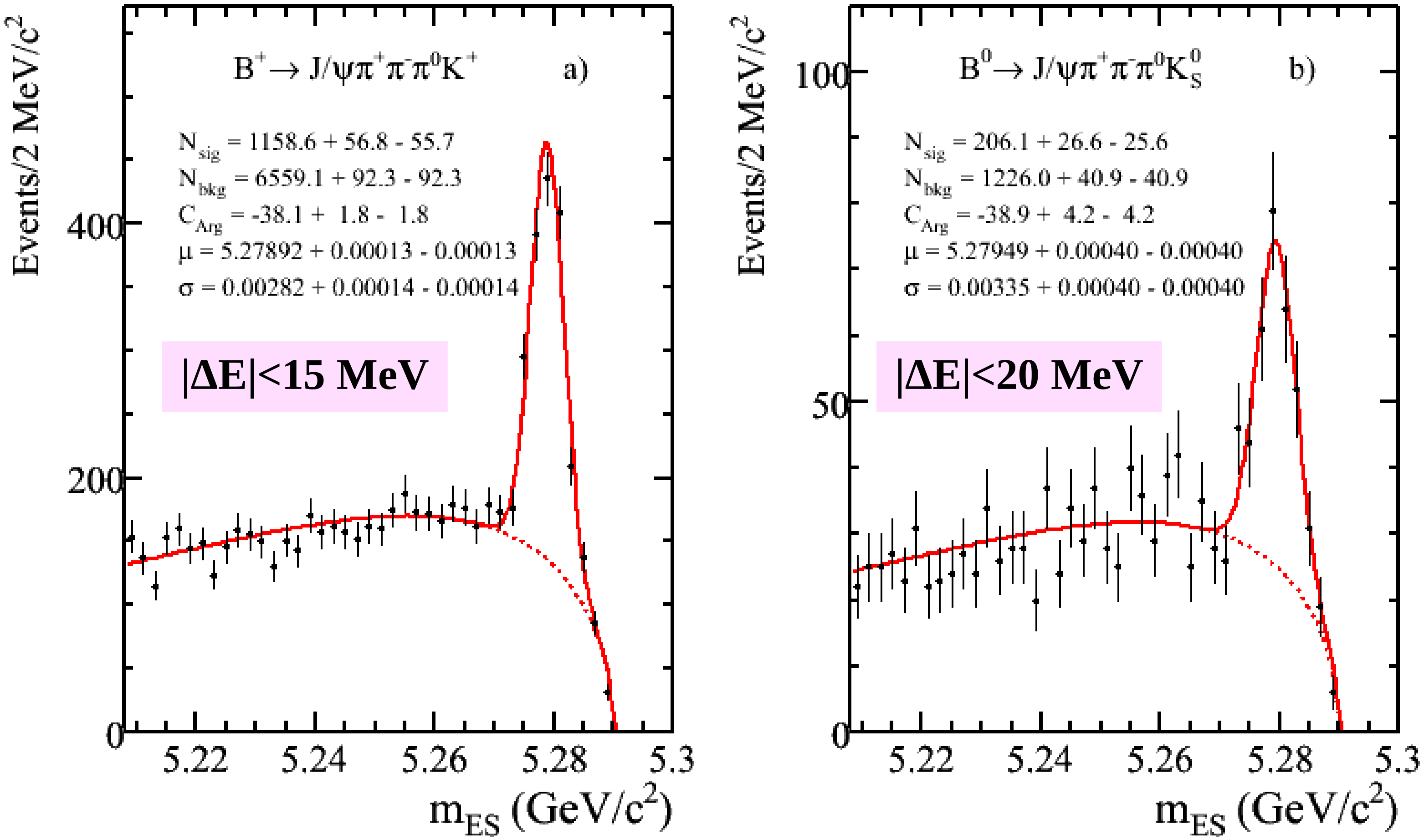


Study of $X(3872) \to J/\psi\omega$

- Efficiency:
  - For B+ (B0), the efficiency increases (decreases) gradually from 6% (5%) close to $m_{J/\psi\omega}$ threshold to 7% (4%) at $m_{J/\psi\omega}$ ~4.8 GeV/c2

- Mass resolution:
  - The resolution changes gradually from 6.5 MeV/c2 at 3.84 GeV/c2, to 9 MeV/c2 at 4.8 GeV/c2

Study of X(3872)→J/ψω



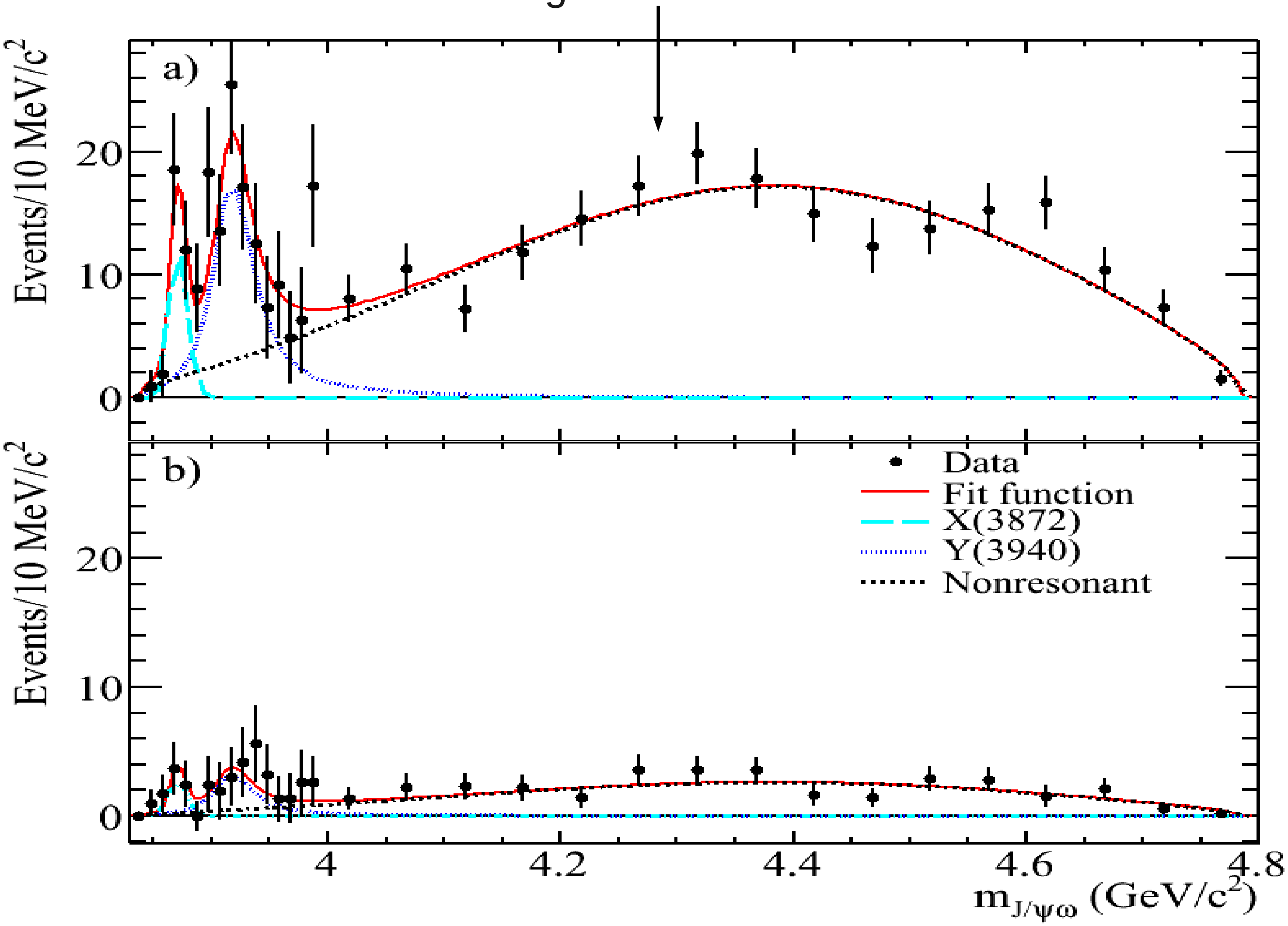
Clear mES signals in both B+ and B0 with ~1160 and ~210 signal events, respectively

Study of $X(3872)\rightarrow J/\psi\omega$

Selection Category	Criterion
$J/\psi\rightarrow\mu\mu$ mass (GeV/c^2)	$3.06<m_{\mu\mu}<3.14$
$J/\psi\rightarrow ee$ mass (GeV/c^2)	$2.95<m_{ee}<3.14$
π^0 mass (GeV/c^2)	$0.115<m_{\gamma\gamma}<0.150$
ΔE (GeV)	$\|\Delta E\|<0.015$ (B^+); $\|\Delta E\|<0.020$ (B^0)
B-helicity angle	$\|\cos\theta_B\|<0.9$
Photon helicity angle θ_γ	$\cos\theta_\gamma<0.95$
$\psi(2S)$ veto (GeV/c^2)	$3.661<m_{J/\psi\pi\pi}<3.711$
mES (GeV/c^2)	5.274 – 5.284 (signal box), >5.2 for fits

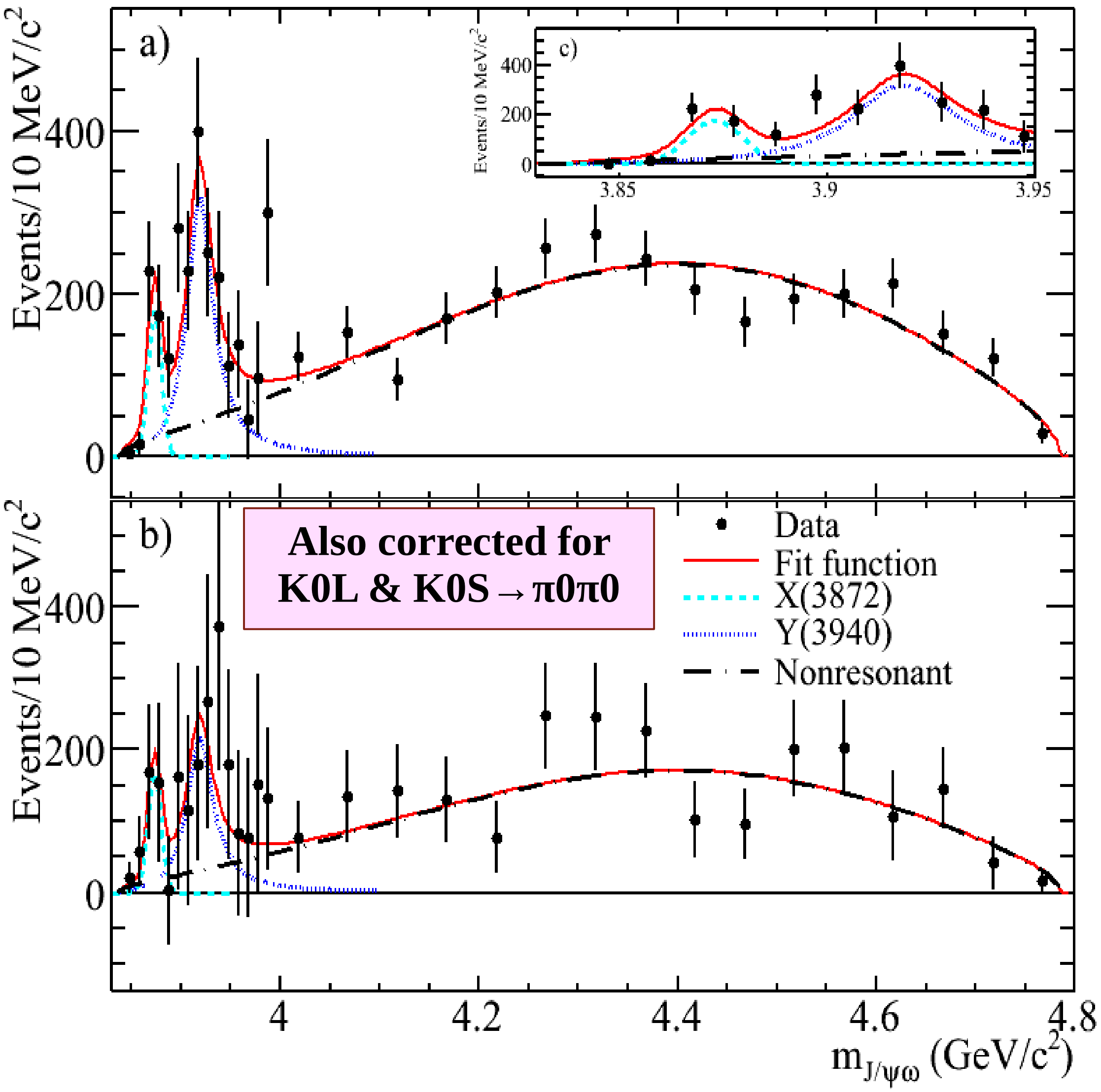
Study of X(3872)→J/ψω

Fitting uncorrected data:



Parameter values (other than normalizations) are consistent with fits to corrected data

Fitting the Efficiency Corrected Data



X(3872) : Gaussian function (resolution)

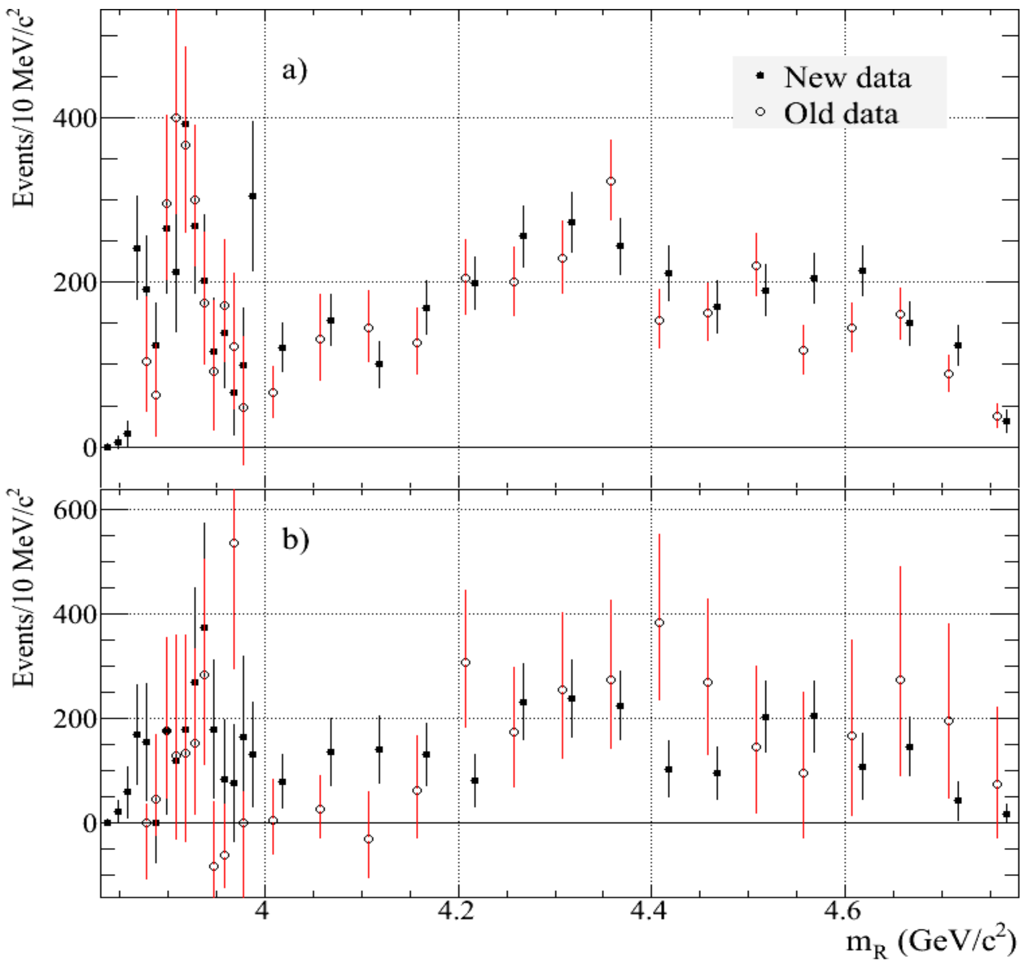
Y(3940): Breit-Wigner function for the × phase space

Nonresonant: phase-space × Gaussian function × mJ/ψω

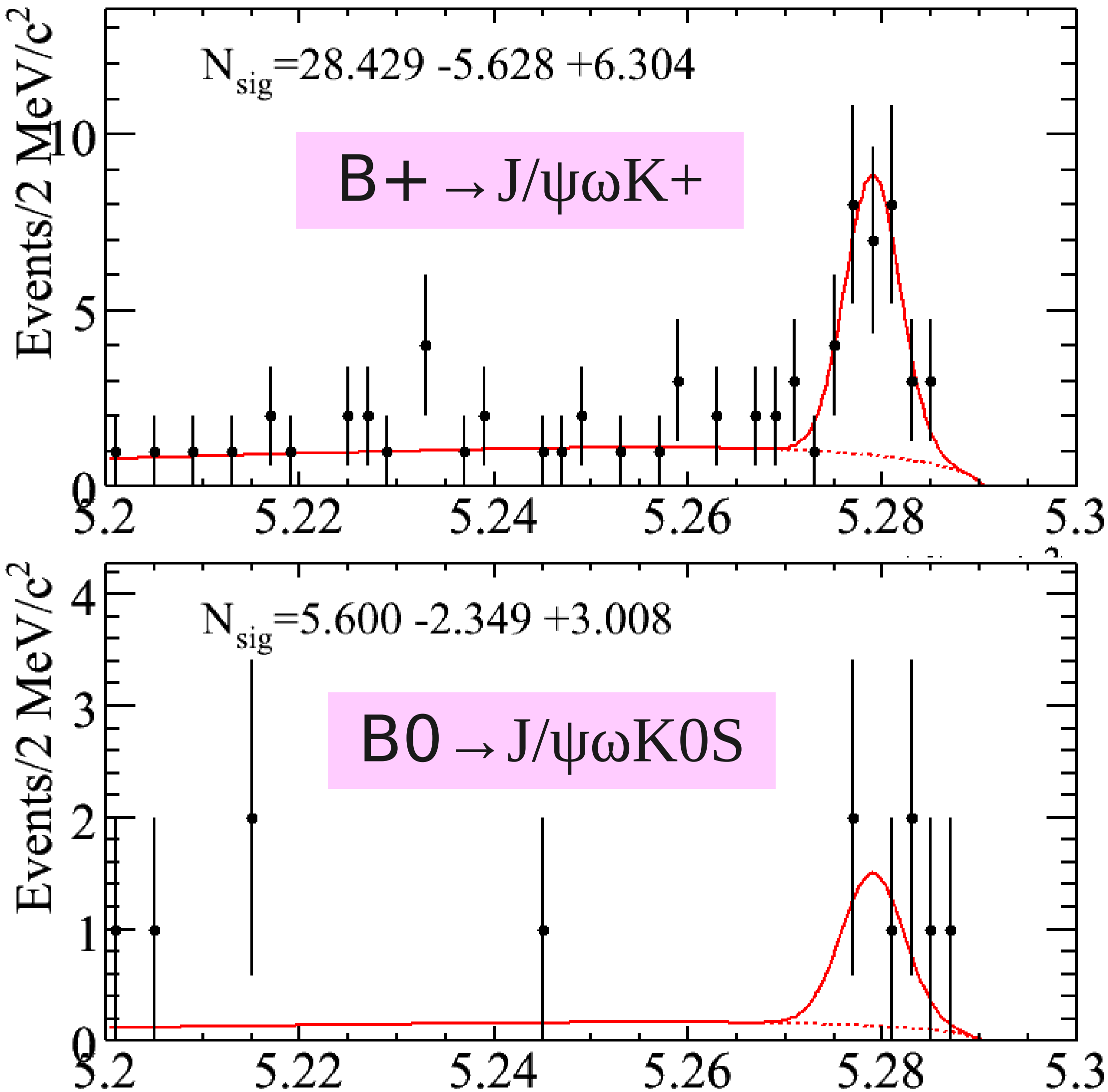
Good fits are obtained

Study of X(3872)→J/ψω

Comparison between old and new data:



Study of X(3872)→J/ψω



mES (GeV/c2)

Events around X(3872)

Events in

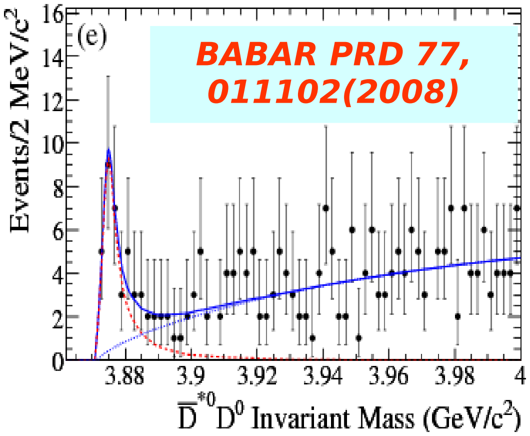
3.8625<mJ/ψω<3.8825 GeV/c2

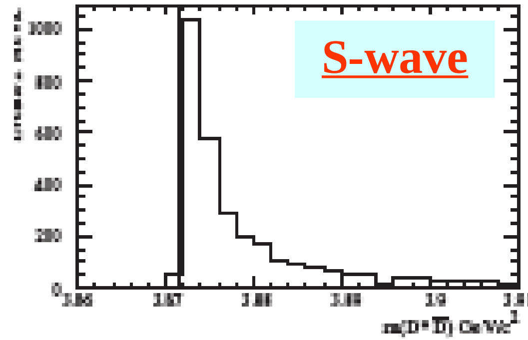
Study of X(3872)→J/ψω

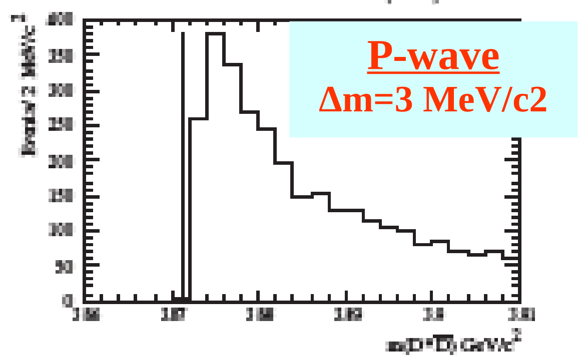
- Both *BaBar* and Belle reported a shift in X(3872) mass in the decay mode X→D0D*0(~3875 MeV/c2) (*No shift* in mass in the most recent analysis from Belle)

- The shift in D0D*0 mass may be due to one unit of orbital angular momentum, as for the ω

- An explanation of the shift for X(3872)→ D0D*0 can be found in *PRL 100, 062006 (2008)*



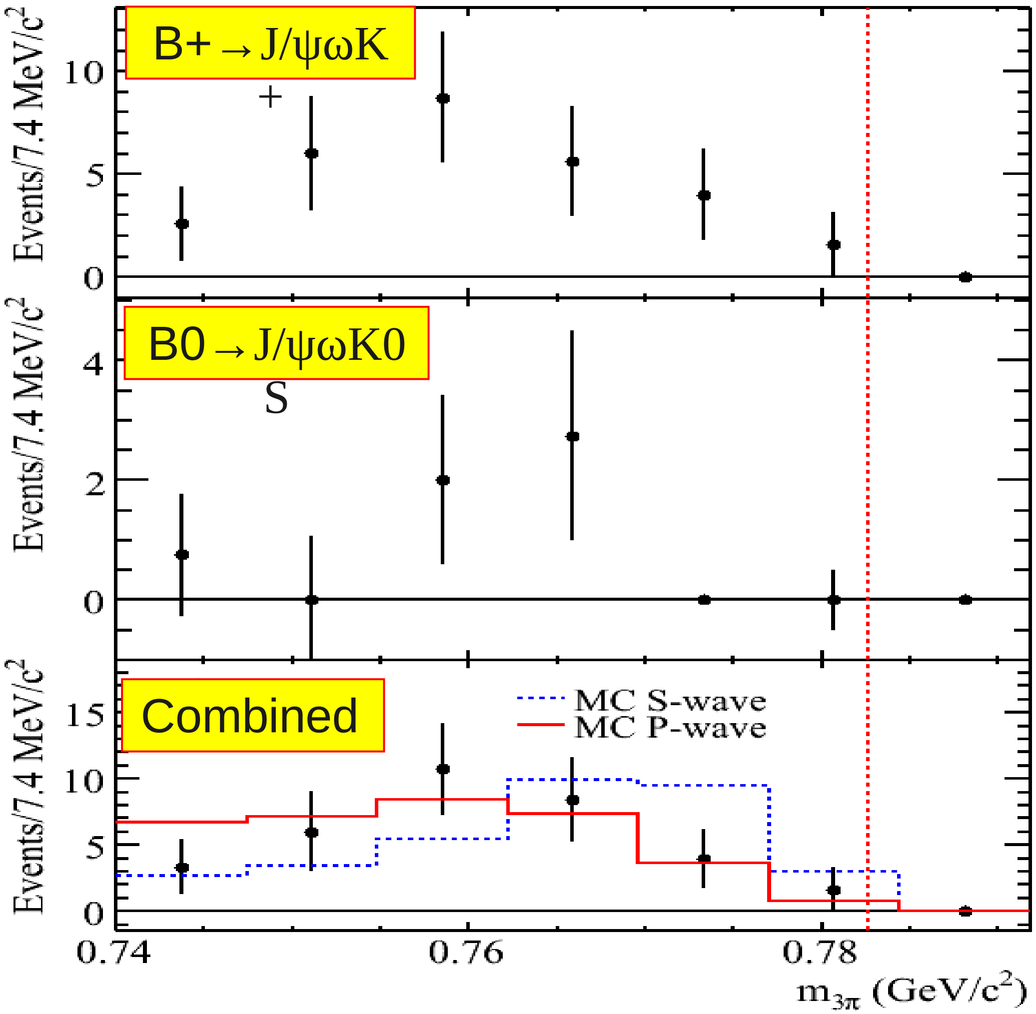




Study of X(3872)→J/ψω

m3π for the X(3872)

PRD 82, 011101 (2010)



Events in X-sig. reg.
3.8625<mJ/ψω<3.8825
GeV/c2

Each point is the signal yield of an mES fit in m3π interval of 7.4 MeV/c2

S-wave: χ2/NDF=10.17/5
P(χ2/NDF)=7%
P-wave: χ2/NDF=3.53/5
P(χ2/NDF)=62%

Similar shift in D0D*0; Explanation for such a shift can be found in PRL *PRL 100, 062006 (2008)*

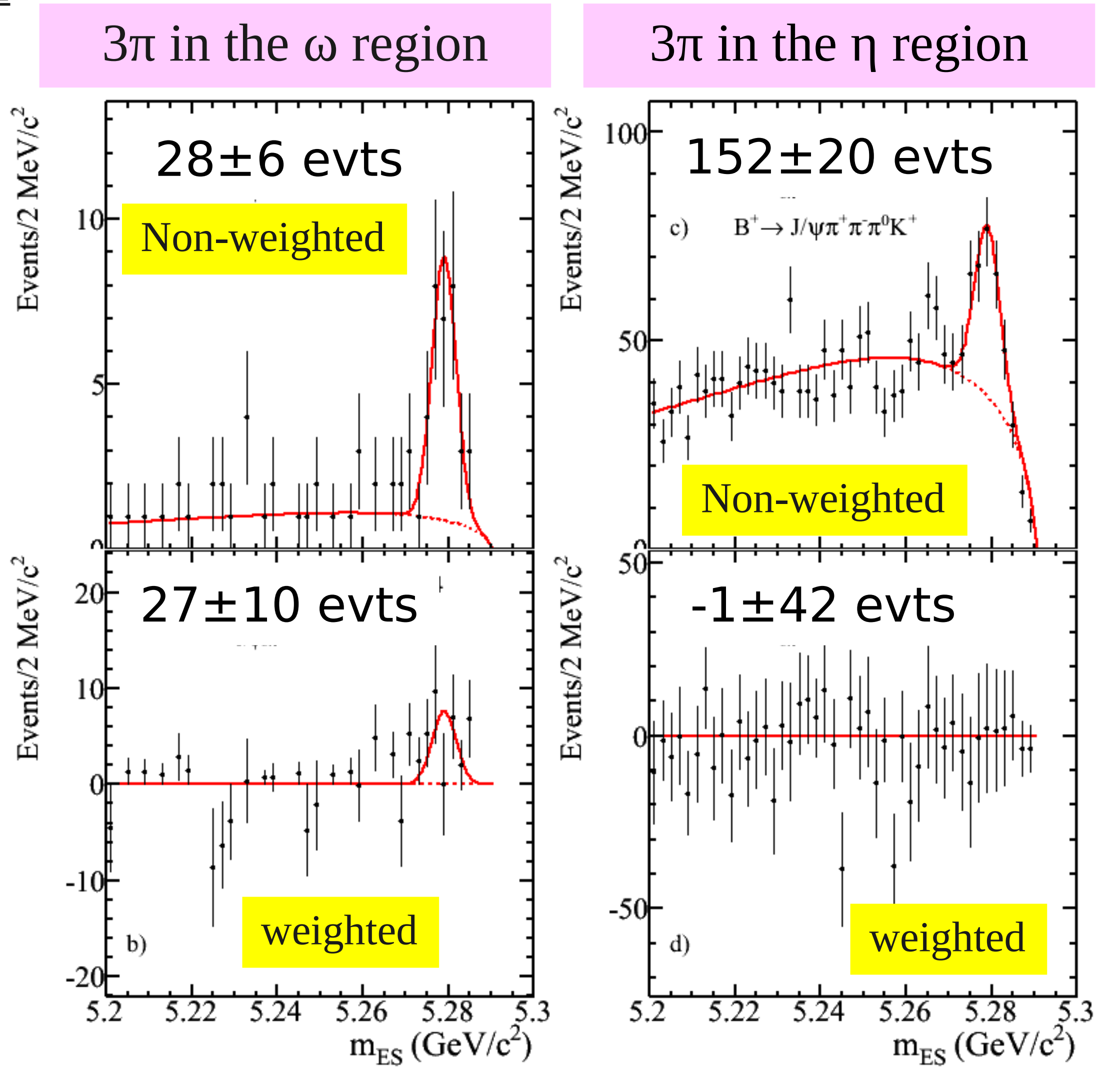
How do we justify calling such a distribution ω signal?

Study of X(3872)→J/ψω

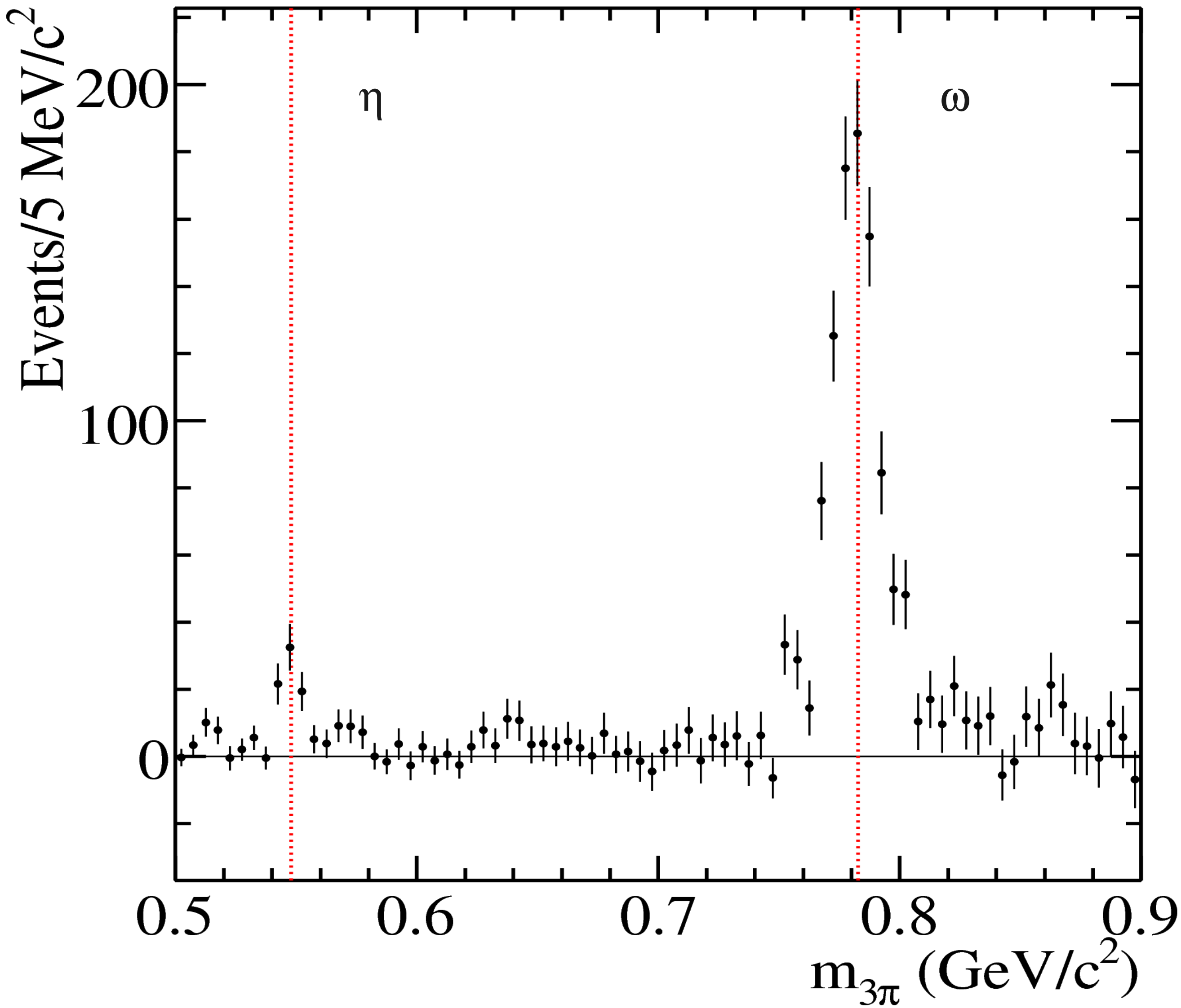
DALITZ PLOT WEIGHTING TECHNIQUE

Each event is given weight of (5/2)(1-3cos2θh), where θh is the angle between the π+ and π0 in the π+π- rest frame

Non-ω events projected away

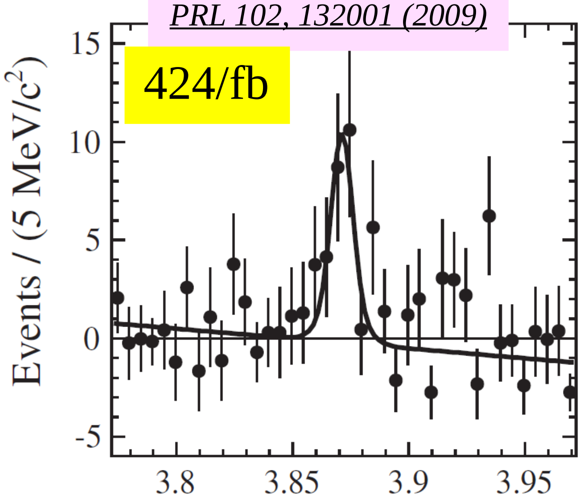


3π invariant mass



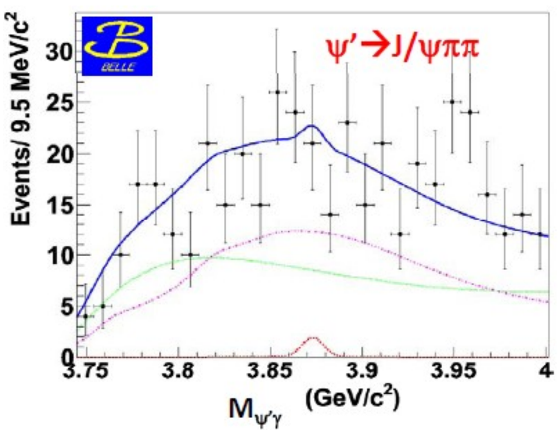
The X(3872) → ψ(2S)γ

- *BaBar* also reports evidence of *X(3872)→ψ(2S)γ in B+→X(3872)K+ at 3.5σ*
- *B → ψ(2S)(Kπ) background is included in MC study*



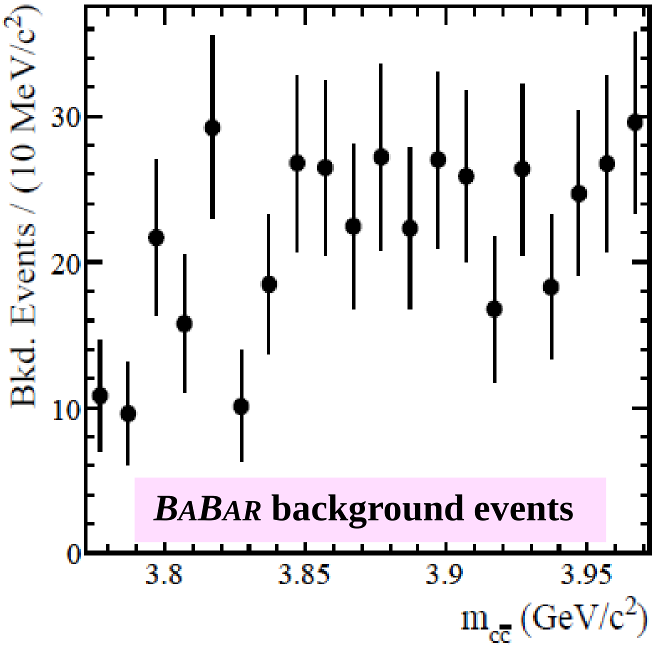
- **Belle** does **<u>not confirm</u>** the existence of the decay mode **X(3872) → γψ(2S)**
- When remove the background due to B → ψ(2S)K*(892), K*(892) → Kπ0, the ψ(2S)γ mass does not show any peak at the X(3872) resonance

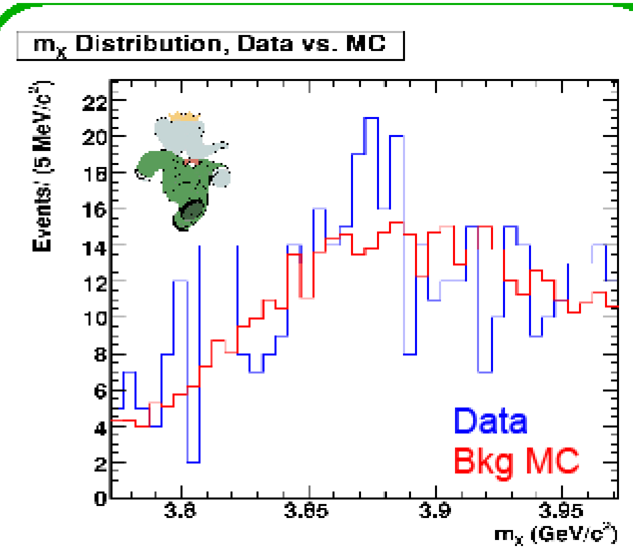
Belle Preliminary 850/fb



BABAR: B → ψ(2S)(Kπ) background is included in MC studies

For more details see:
PRL 102, 132001 (2009) & B. Fulsom UBC Thesis (SLAC-R-949)





Raw $\psi(2S)\gamma$ mass distribution

Remarks on the X(3872)

- X(3872) → ψγ ⇨ C=+1
- No charged partner found for $X(3872)^-$ ➔ I=0
- X(3872) quantum numbers
  - Belle: $J^{PC}=1^{++}$ favored (ω-ρ interference is not included)
  - CDF: ππ mass distribution analysis and the angular distribution study ➔ $J^{PC}=1^{++}$ or 2^{-+}
  - BaBar: $J^{PC}=2^{-+}$ favored
- What is the nature of X(3872)?
  - Hybrid?.... BUT $m(c\bar{c}g)>4.2 GeV/c^2$
  - Tetraquark?... BUT
    No evidence for charged $X(3872)^{\pm}$
  - Charmonium?... mass is OK for 2^{-+} state (η_{c2}, the $^1D_2$ cc ground state)
  - Molecular?
    - $m(D^0) + m(D^{0*}) = 3871.8 \pm 0.4$ MeV/c^2
    - Decays to X(3872) → J/ψρ, $D^0\bar{D}^{0*}$, J/ψω expected; but we observe X → ψ(2S)γ
    - Compatible with $J^{PC} = 1^{++}, 2^{-+}$ assignment

Belle: arXiv:0505038
BaBar: PRD 74, 071101(2006)
PRL 102, 132001 (2009))

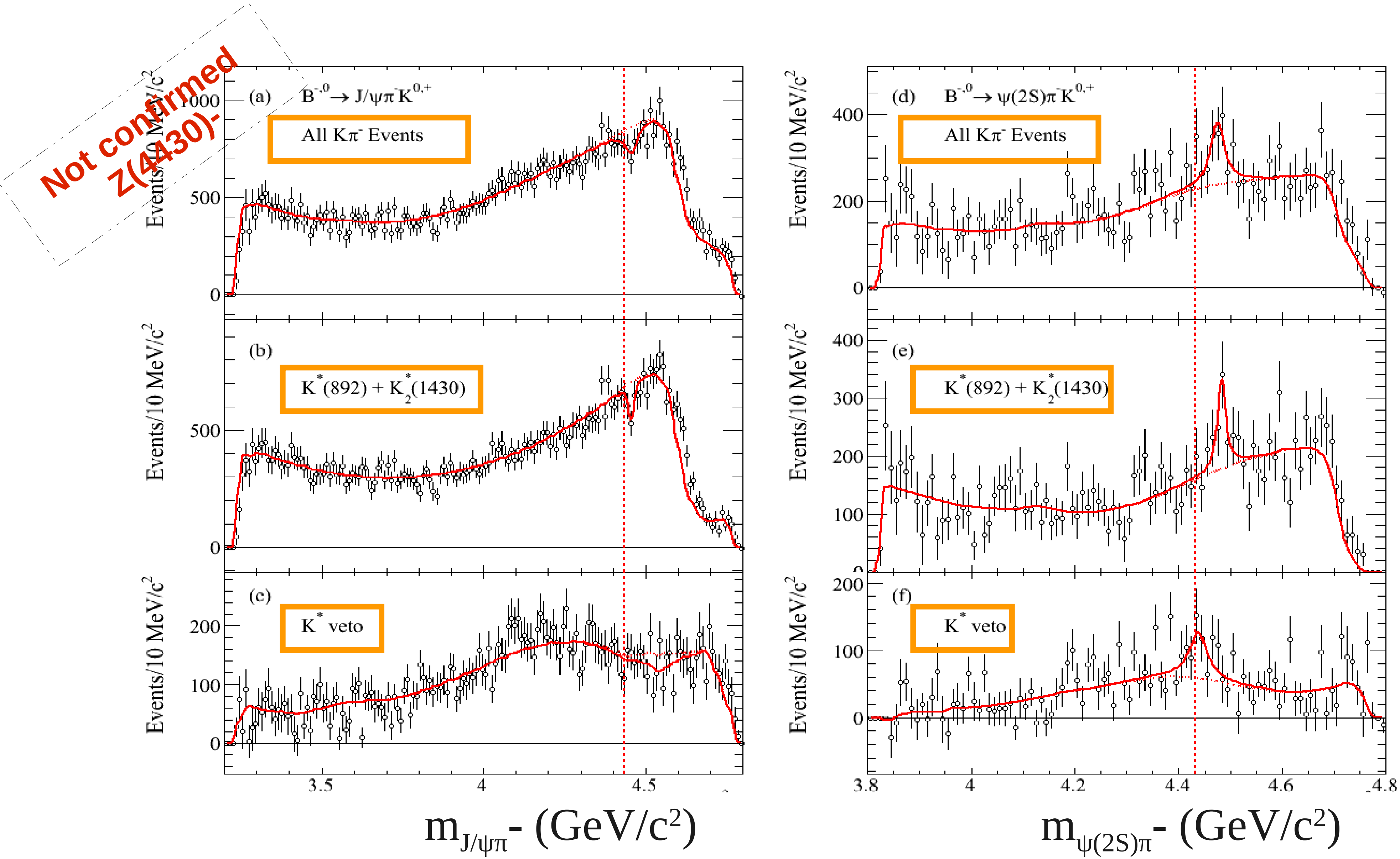
BABAR: PRD 73, 011101 (2006)

Belle: arXiv:0505038

CDF: PRL 96, 102002 (2006)
PRL 98, 132002 (2007)

- **R(B0/B+) = 0.50±0.30±0.05 in J/ψ π π**
- **R(B0/B+) = 1.33±0.69±0.52 in $D^0\bar{D}^{*0}$**
- **R(B0/B+) = 0.8±0.3 in J/ψω**
- Δm =2.7±1.3±0.2 MeV/c^2 in **J/ψ π π**
- Δm =0.7±1.9±0.3 MeV/c^2in **$\bar{D}^0D^{*0}$**
- M_X = 3871.4±0.6 MeV/c^2 **in J/ψ π π**
- M_X= 3875.1±1.1 MeV/c^2 **in $\bar{D}^0D^{*0}$**
- $M_x = 3873.0^{+1.8}_{-1.6} \pm 1.3$ **in J/ψω**

Summary of the main results: B →Z K



Branching fraction product for entire decay chain,

$\Upsilon(3S) \rightarrow \gamma\chi_{bJ'}(2P) \rightarrow 2\gamma\Upsilon(1^3D_J) \rightarrow 2\gamma\pi^+\pi^-\Upsilon(1S) \rightarrow 2\gamma\pi^+\pi^-l^+l^-$,

and for the dominant modes only:

$\chi_{bJ'}(2P)$	1^3D_J	Product BF	90% C.L. upper limit
J'=1	J=1	$(1.27_{-0.69}^{+0.81} \pm 0.28) \times 10^{-7}$	$< 2.50 \times 10^{-7}$
J'=1	J=2	$(4.9_{-1.0}^{+1.1} \pm 0.3) \times 10^{-7}$	
J'=2	J=3	$(1.34_{-0.83}^{+0.99} \pm 0.24) \times 10^{-7}$	$< 2.80 \times 10^{-7}$

CLEO upper limit: $< 6.6 \times 10^{-6}$