Studies of Radiative Decays and Search for X(3872) at BABAR

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On behalf the *BABAR* Collaboration

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Outline

- Search for ξ(2230) @ *BABAR* (***NEW: Submitted to PRL*** ***hep-ex/1007.3526***)
- Evidence for X(3872)→J/ψω (***PRD 82, 011101 (2010)***)

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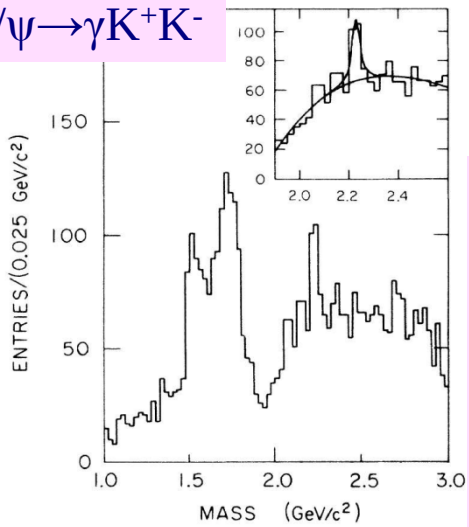
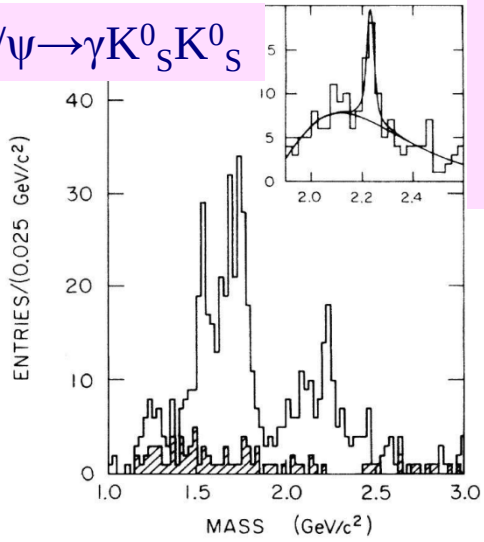
The ξ(2230)

- **Mark-III Collaboration** reported a narrow resonance in radiative J/ψ decays (m~2230 MeV/c^2; Γ~20 MeV; Significance 3.6σ-4.5σ)
- MIS ITEP Collaboration claimed observation of ξ(2230) in $\pi^- p \to K^0_S K^0_S n$ **(Pos HEP2005, 083 (2006))**
- Crystal Barrel Collaboration did not observe it in $p\bar{p} \to \pi^0\pi^0, \pi^0\eta$ **(PLB 520, 175 (2001))**
- BES could not confirm or refute the existence of ξ(2230) **(PRL 76, 3502 (1996) & PRL 81, 1179 (1998))**
- Lattice QCD: resonance with mass ~2.2 GeV/c^2 for the ground state tensor 2^{++} glueball **(PRD 69, 076003 (2004) & PRD 56, 4043 (1997))**

$J/\psi \to \gamma K^+K^-$



$J/\psi \to \gamma K^0_S K^0_S$



Mark-III: PRL 56, 107 (1986)

Search for the ξ(2230) @ BABAR [hep-ex/1007.3526]

- **BABAR searched** for ξ(2230) in the decay $e^+e^- \to \gamma_{ISR} J/\psi$, $J/\psi \to \gamma\xi(2230)$, $\xi(2230) \to KK$, using **460/fb** of data (425 (35) /fb @ $\sqrt{s}$=10.54 (10.5) GeV)

- The dataset contains $(16.4 \pm 0.3) \times 10^6$ J/ψ decays
- The J/ψ and K^0_S masses are constrained to the PDG values

- Selection criteria:
  - ✓ Eγ>300 MeV & Veto events with π^0 candidates
  - ✓ Events with two tracks only
  - ✓ P(K)>1.35 GeV/c to suppress events of $J/\psi \to K^*(892)K$, $K^*(892) \to K\pi$
  - ✓ Helicity angle of each Kaon $|\cos\theta_h K|<0.7$
- γKK mass resolution is 6 (8) MeV/c^2 for the neutral and the charged modes

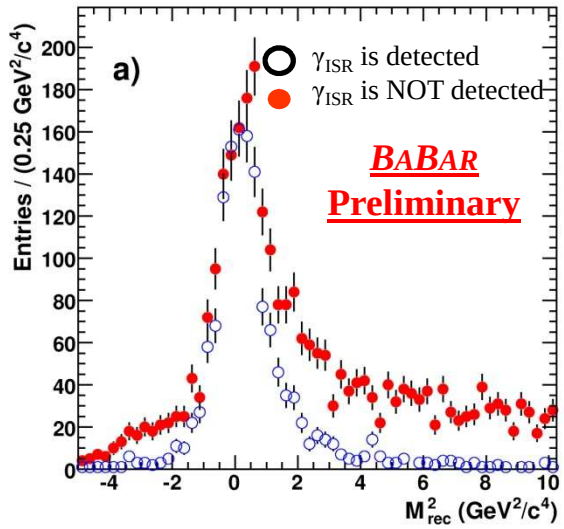
- Number of selected events:

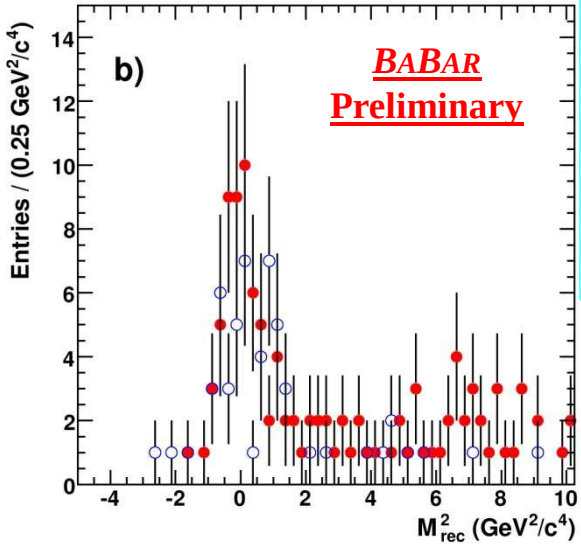
	γK^+K^-	$\gamma K^0_S K^0_S$
γ_{IRS} detected	~1000	~80
γ_{IRS} not detected	~1300	~100

Search for the ξ(2230) @ BABAR

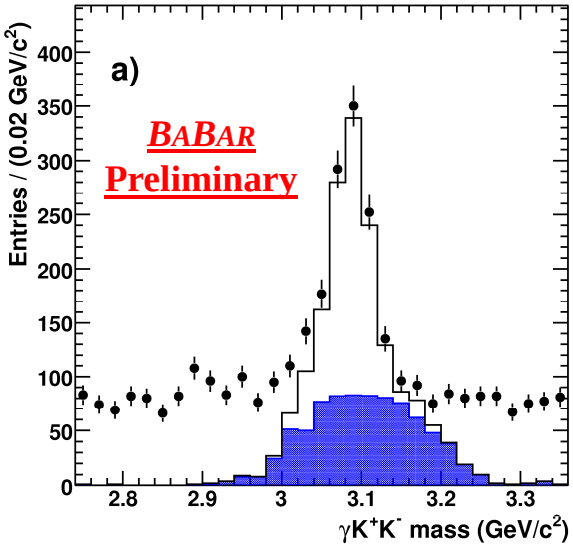
hep-ex/1007.3526

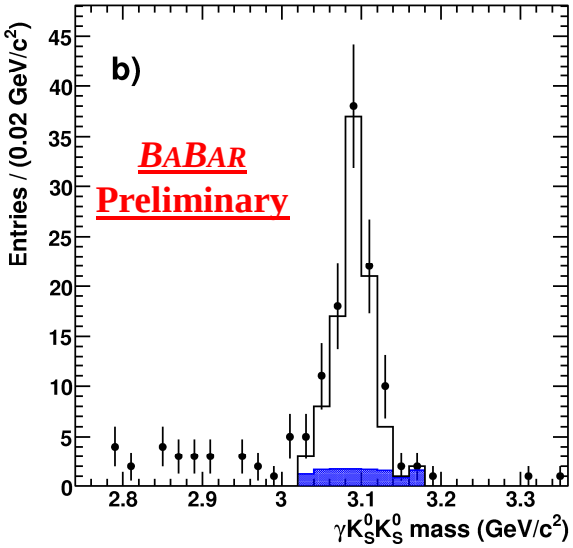
$P_{ISR} = P_{e+e-} - P_{J/\psi}$





- The recoil mass peaks at zero in both decay modes: $J/\psi \rightarrow \gamma K^+K^-$ and $J/\psi \rightarrow \gamma K^0_S K^0_S$
- Clear J/ψ resonance are obtained with a flat continuum background

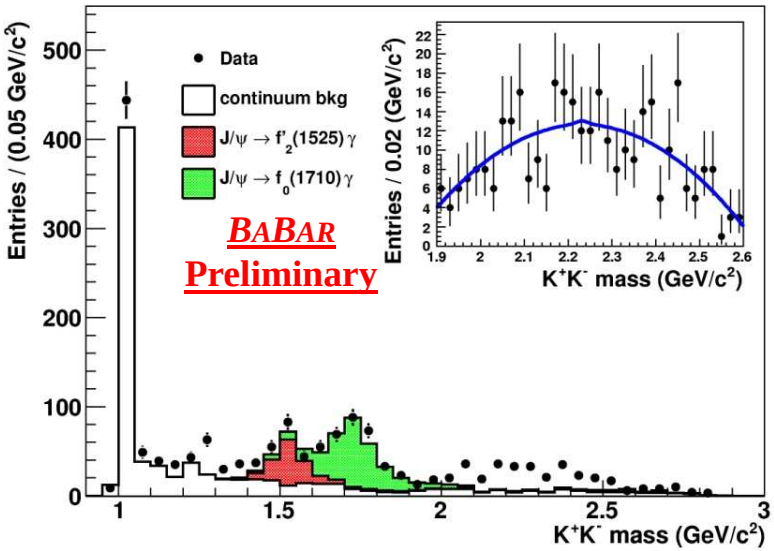


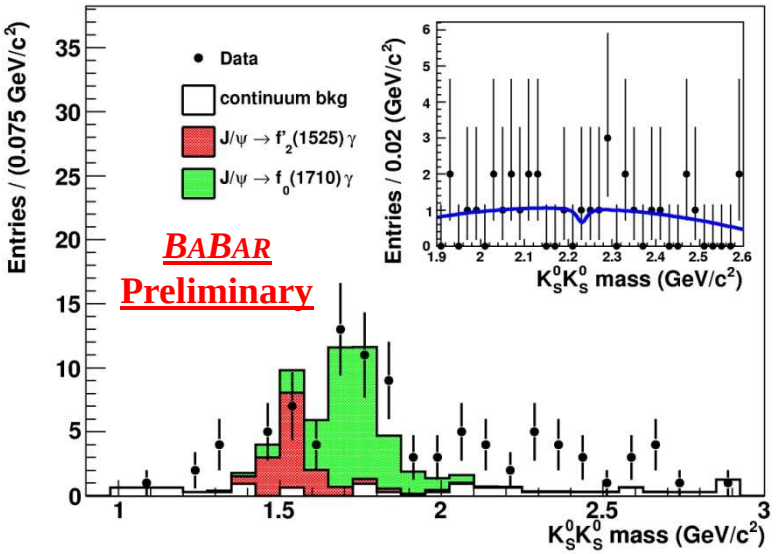


Search for the ξ(2230) @ BABAR

- Contributions from $J/\psi \to \gamma f2(1270)$, $\gamma f'_2(1525)$, $\gamma f_0(1710)$, $K^*(892)K$ are obtained
- Signal: BW convolved with resolution
- Background: Second order Chebychev polynomial
- **No evidence** for ξ(2230) was observed
- Branching fractions (BF's) vary with the spin and helicity hypothesis
- Obtained branching fraction upper limits:
  - $BF(J/\psi \to \gamma\xi) \times BF(\xi \to K^+K^-) < 3.6 \times 10^{-5}$ @ 90% C.L. (J=2; h=±1)
  - $BF(J/\psi \to \gamma\xi) \times BF(\xi \to K^0_S K^0_S) < 2.9 \times 10^{-5}$ @ 90% C.L. (J=2; h=0)
- ***BABAR*** upper limits BF's are **below** the **Mark-III** values
- **Only** J=2 & h=0 is **compatible** with the BES results

hep-ex/1007.3526





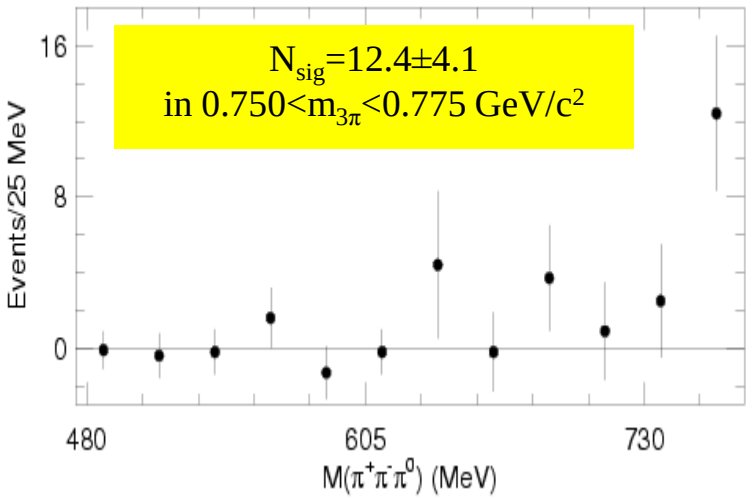
The X(3872)

- X(3872): first new charmonium-like state discovered at the B-factories by Belle in B→XK, $X \to J/\psi \pi^+ \pi^-$
- Confirmation from: CDF, D0, & *BABAR*
- So far, the X is the only new charmonium-like state observed with more than one decay mode: $X \to J/\psi\gamma$, $X \to \psi(2S)\gamma$, $X \to D^0 \bar{D}^{0*}$, and $J/\psi \pi^+ \pi^-$ (assuming different X, Y, and Z states)
- The decay modes: $X \to J/\psi\gamma$ & $X \to \psi(2S)\gamma$ ➔ C=+1
- No charged partner for the X ➔ I=0
- J^P for the X was studied by Belle & CDF using $X \to J/\psi \pi^+ \pi^-$; CDF showed that couldn't distinguish between 1^+ and 2^-

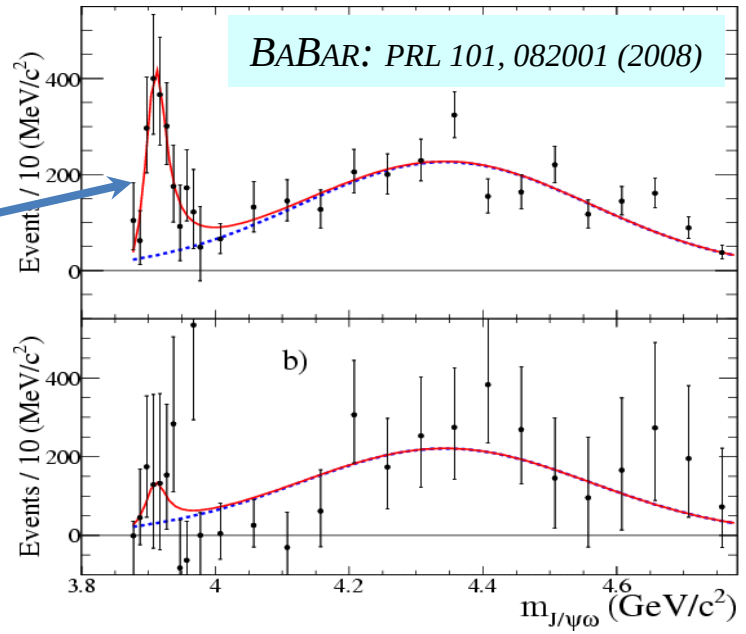
$X(3872) \rightarrow J/\psi\omega$?

- Belle reported an excess of events in $m_{3\pi}$ above 750 MeV/c^2 in the decay $B \rightarrow J/\psi 3\pi K$ for $|m_{J/\psi 3\pi}-3872|<16.5$ MeV/c^2 ➔ interpreted as $X \rightarrow J/\psi\omega$

Belle: *hep-ex/0505037*



- *BABAR*, confirmed the existence of the Y(3940) in $B \rightarrow Y(J/\psi\omega)K$ but could not see the $X(3872) \rightarrow J/\psi\omega K$ signal when requiring ***0.7695< $m_{3\pi}$<0.7965*** *(B^+)*



Y(3940)!

m=3914.6$_{-3.4}^{+3.8}$(stat)±2.0(syst) MeV/c^2

Γ=34$_{-8}^{+12}$(stat)±5(syst) MeV

Product B.F.(B+)=[4.9$_{-0.9}^{+1.0}$(stat)±0.5(syst)]×10^{-5}

Product B.F.(B0)=[1.3$_{-1.1}^{+1.3}$(stat)±0.2(syst)]×10^{-5}

The Method

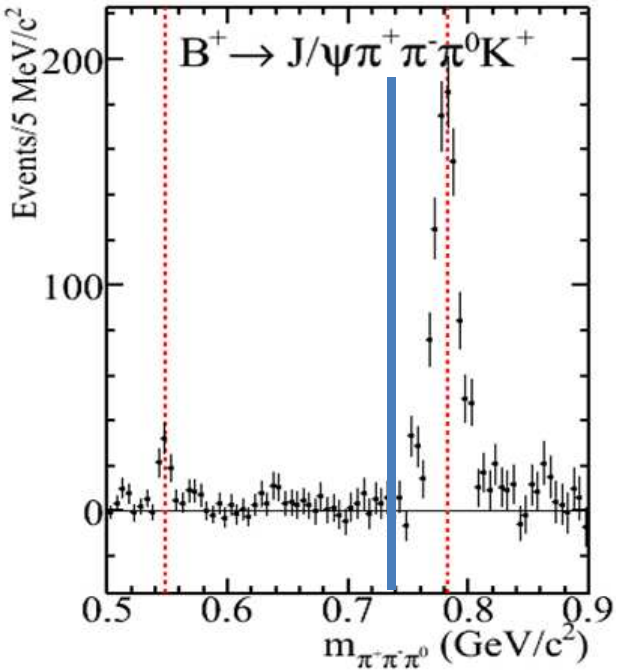
PRD 82, 011101 (2010)

- We use the same selection criteria used in the previous *BABAR* analysis (PRL 101, 082001 (2008)), except that on the lower-mass limit of the ω signal region
- Fit m_{ES} in intervals of variable of interest to extract the B-related signal (after ΔE requirement)

$$m_{ES} = \sqrt{\left(\frac{\frac{s}{2} + \vec{P}_{e^+e^-} \cdot \vec{P}_B}{E_{e^+e^-}}\right)^2 - \vec{P}_B^{\,2}} \sim m_B$$

$$\Delta E = E_B^* - \frac{\sqrt{s}}{2}$$

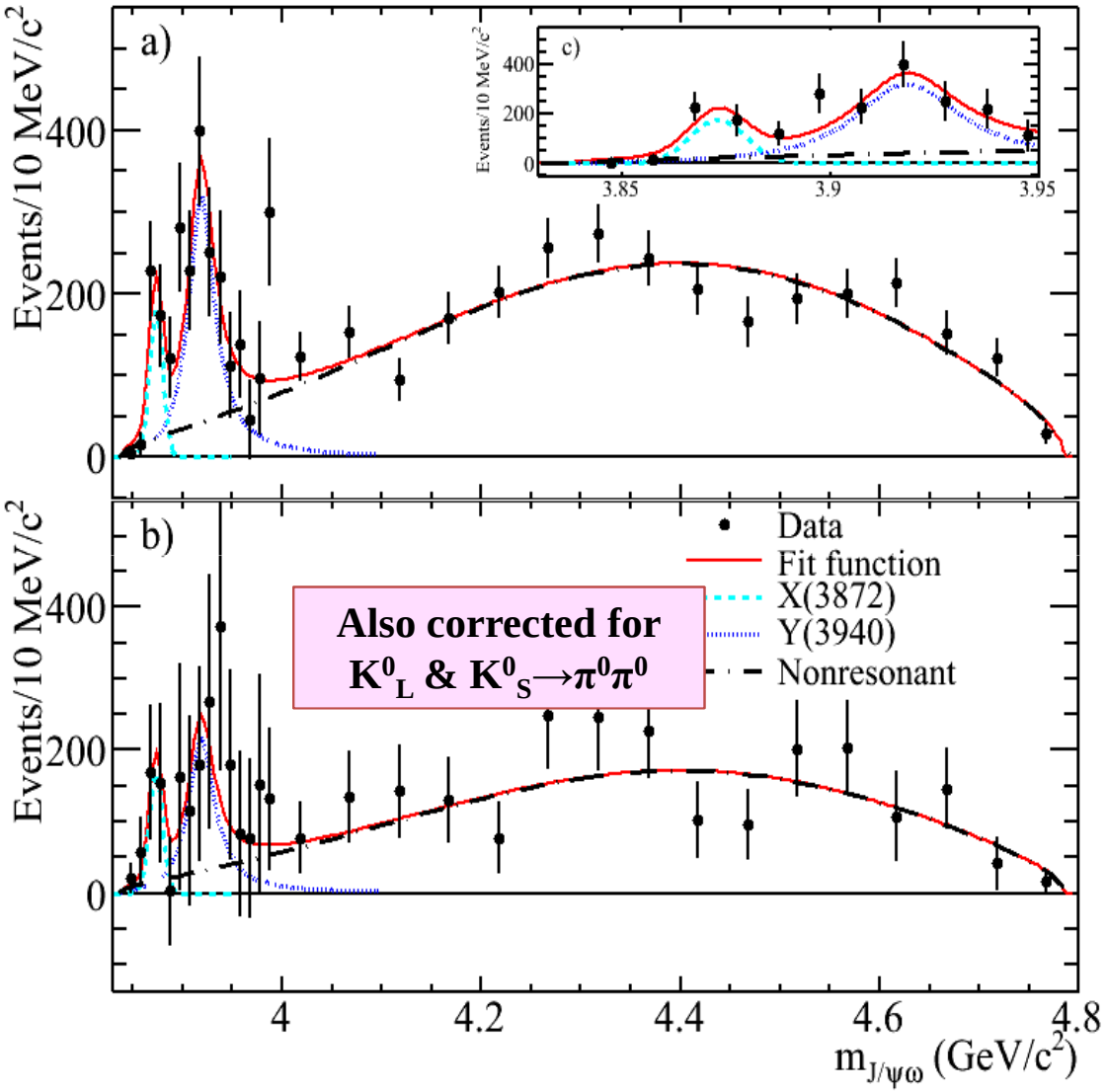
- The data (signal yields) are corrected for efficiency and K^0 branching fractions to perform a simultaneous fit to the B^+ and B^0 distributions* of $m_{J/\psi\omega}$



Criterion (GeV/c²)	
$0.7695<m_{3\pi}<0.7965$ (B^+)	*Old analysis*
$0.7605<m_{3\pi}<0.8055$ (B^0)	
0.7400$<m_{3\pi}<$0.7965 (B^+)	*New analysis*
0.7400$<m_{3\pi}<$0.8055 (B^0)	

** The use of charge conjugate reactions is implied throughout*

Fitting the Efficiency Corrected Data



PRD 82, 011101 (2010)

X(3872) : Gaussian function (resolution)

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

Nonresonant: phase-space × Gaussian function × $m_{J/\psi\omega}$

Good fits are obtained

Fit Results

PRD 82, 011101 (2010)

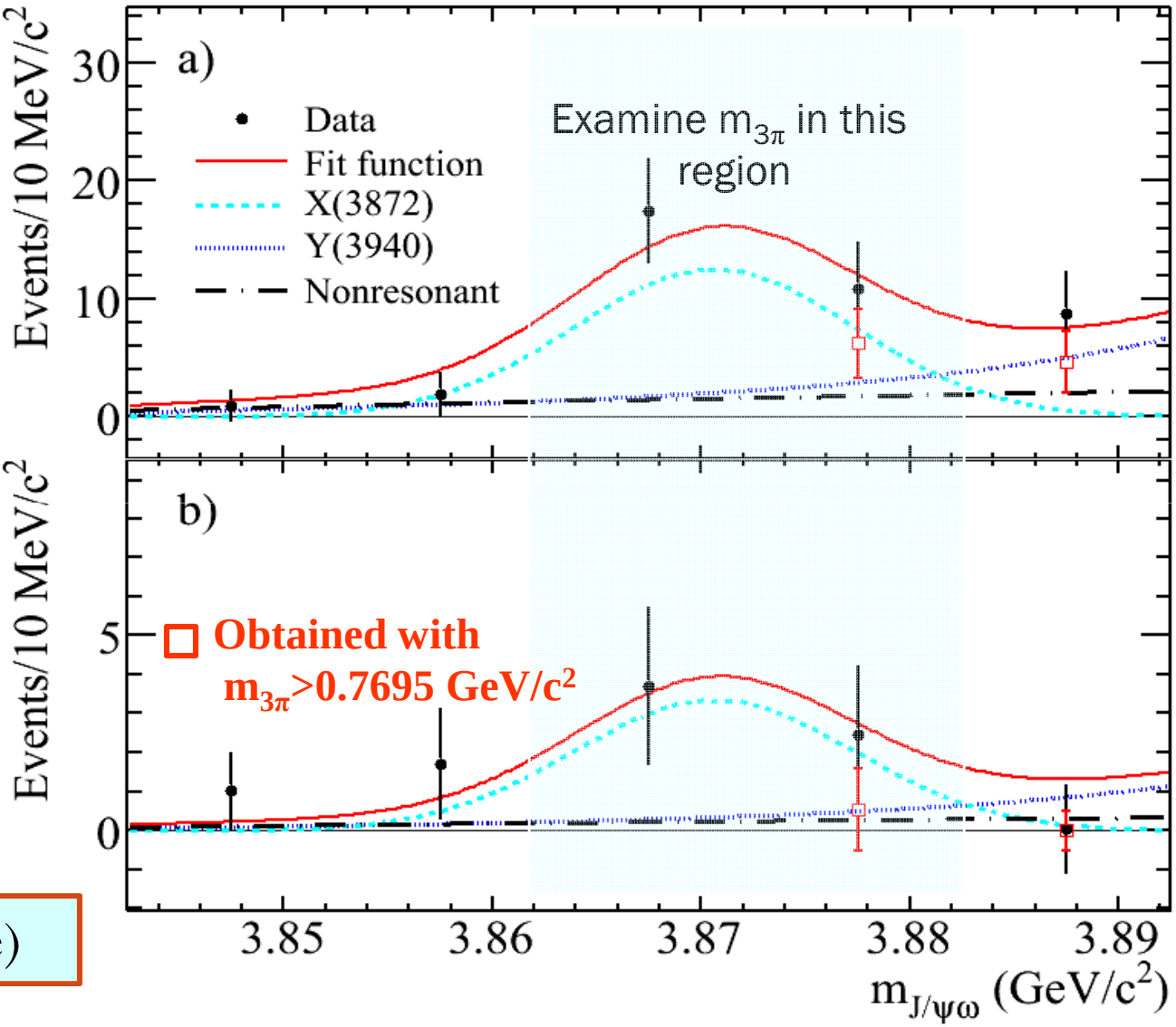
Fit Parameter	Value
m_X (GeV/c^2)	$3873.0_{-1.6}^{+1.8}$(stat)$\pm$1.3(syst)
m_Y (GeV/c^2)	$3919.1_{-3.4}^{+3.8}$(stat)$\pm$2.0(syst)
Γ_Y (MeV)	31_{-8}^{+10}(stat) $\pm$5(syst)
Gaussian μ (GeV/c^2)	4435_{-30}^{+35}(stat)
Gaussian σ (GeV/c^2)	356_{-38}^{+35}(stat)
N^+_X (N^0_X)	21$\pm$7 (6$\pm$3(stat))
N^+_Y (N^0_Y)	108_{-23}^{+25}(stat) (19$\pm$8(stat))
N^+_{BKG} (N^0_{BKG})	992$\pm$46(stat) (155$\pm$18(stat))
$R_X = N^0_x/N^+_x$	**$1.0_{-0.6}^{+0.8}$(stat)$_{-0.2}^{+0.1}$(syst)**
$R_Y = N^0_Y/N^+_Y$	$0.7_{-0.3}^{+0.4}$(stat) $\pm$0.1(syst)
$R_{BKG} = N^0_{BKG}/N^+_{BKG}$	0.7$\pm$0.1(stat) $\pm$0.1(syst)

Uncorrected Data in the X(3872) Region

PRD 82, 011101 (2010)

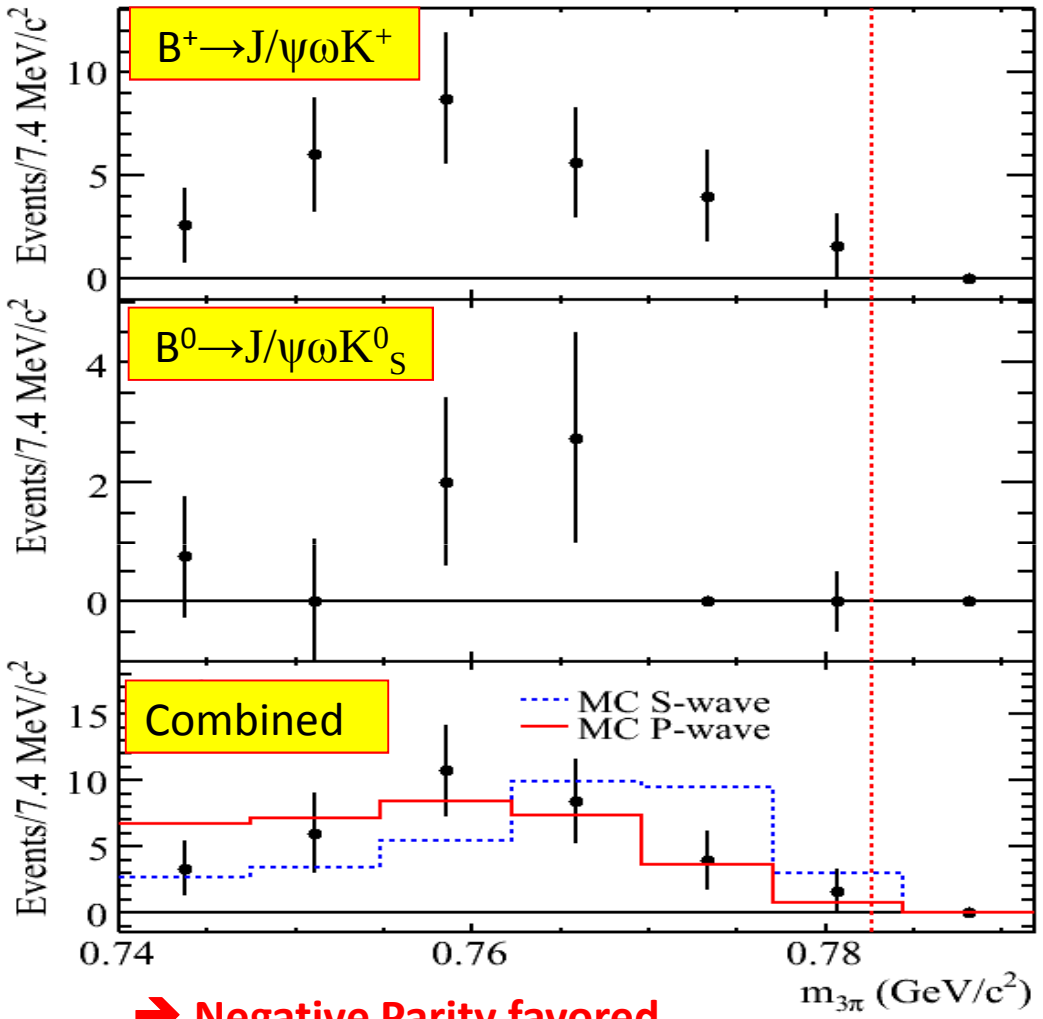
Clear enhancement is observed around $m_{J/\psi\omega}$~3.872 GeV/c^2

(4.0σ significance)



$m_{3\pi}$ for the X(3872)

PRD 82, 011101 (2010)



➔ **Negative Parity favored**

How do we justify calling such a distribution ω signal?

Events in X-sig. reg.
$3.8625 < m_{J/\psi\omega} < 3.8825$ GeV/c^2

Each point is the signal yield of an m_{ES} fit in $m_{3\pi}$ interval of 7.4 MeV/c^2

S-wave: χ^2/NDF=10.17/5
P(χ^2/NDF)=7%
P-wave: χ^2/NDF=3.53/5
P(χ^2/NDF)=62%

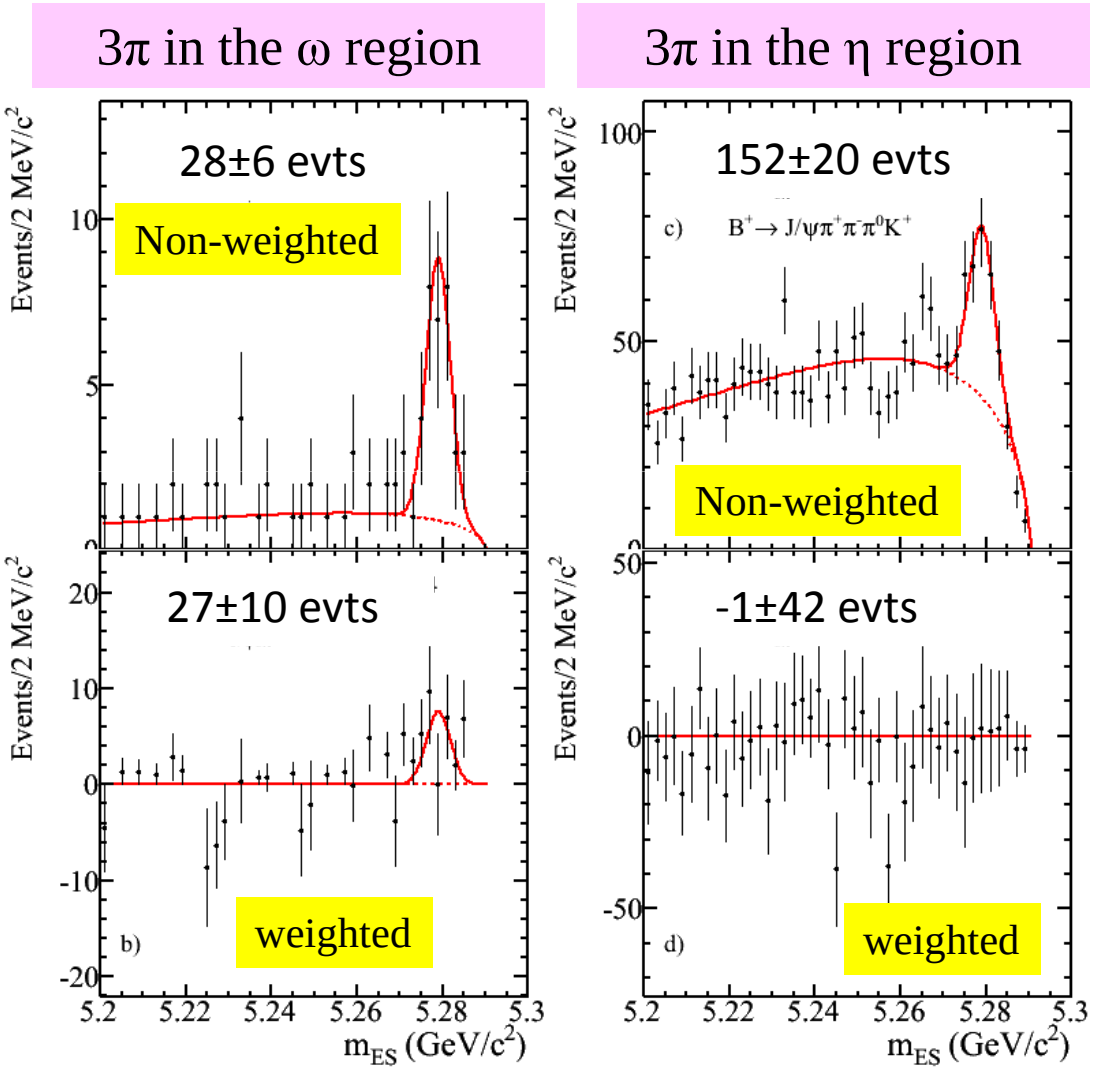
Similar shift in $D^0\bar{D}^{*0}$; Explanation for such a shift can be found in PRL *PRL 100, 062006 (2008)*

Dalitz-Plot Weighting Technique

PRD 82, 011101 (2010)

Each event is given weight of (5/2)(1-$3\cos^2\theta_h$), where θ_h is the angle between the π^+ and π^0 in the $\pi^+\pi^-$ rest frame

Non-ω events projected away



Branching Fractions

PRD 82, 011101 (2010)

Process	Branching Fraction (BF)
$B^+ \to XK^+$, $X \to J/\psi\omega$	$[0.6 \pm 0.2(\text{stat}) \pm 0.1(\text{syst})] \times 10^{-5}$
$B^0 \to XK^0$, $X \to J/\psi\omega$	$[0.6 \pm 0.3(\text{stat}) \pm 0.1(\text{syst})] \times 10^{-5}$
$B^+ \to YK^+$, $Y \to J/\psi\omega$	$[3.0_{-0.6}^{+0.7}(\text{stat})_{-0.3}^{+0.5}(\text{syst})] \times 10^{-5}$
$B^0 \to YK^0$, $Y \to J/\psi\omega$	$[2.1 \pm 0.9(\text{stat}) \pm 0.3(\text{syst})] \times 10^{-5}$
$B^+ \to J/\psi\omega K^+$	$[3.2 \pm 0.1(\text{stat})_{-0.3}^{+0.6}(\text{syst})] \times 10^{-4}$
$B^0 \to J/\psi\omega K^0$	$[2.3 \pm 0.3(\text{stat}) \pm 0.3(\text{syst})] \times 10^{-4}$

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

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

***BABAR average*: 0.8 ± 0.3**

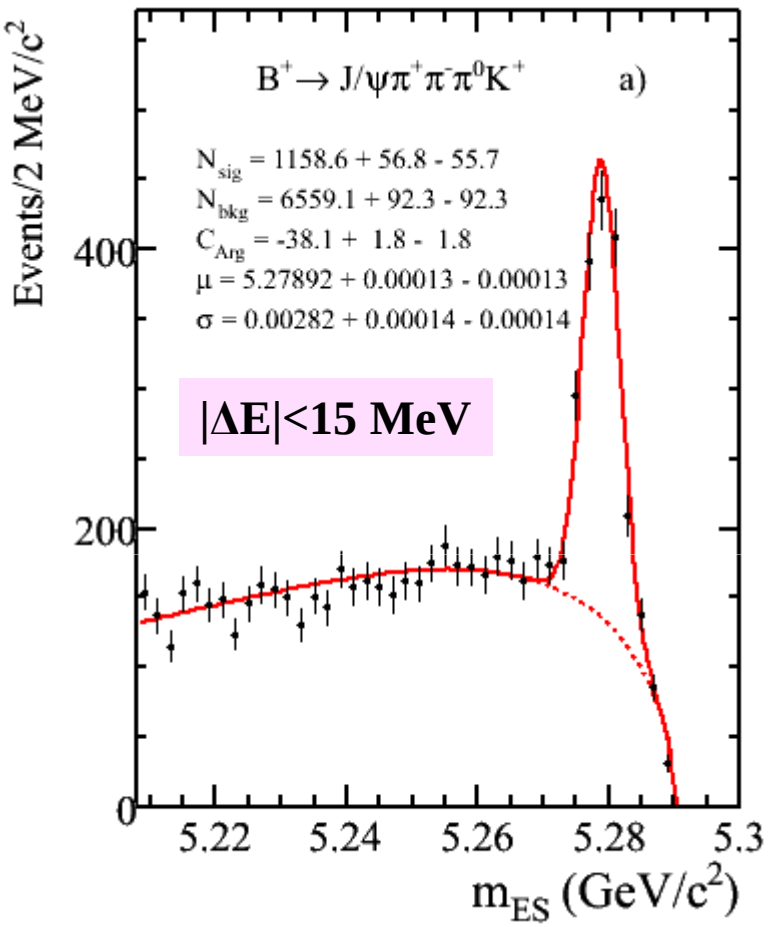
Belle: $1.0 \pm 0.4 \pm 0.3$
hep-ex/0505037

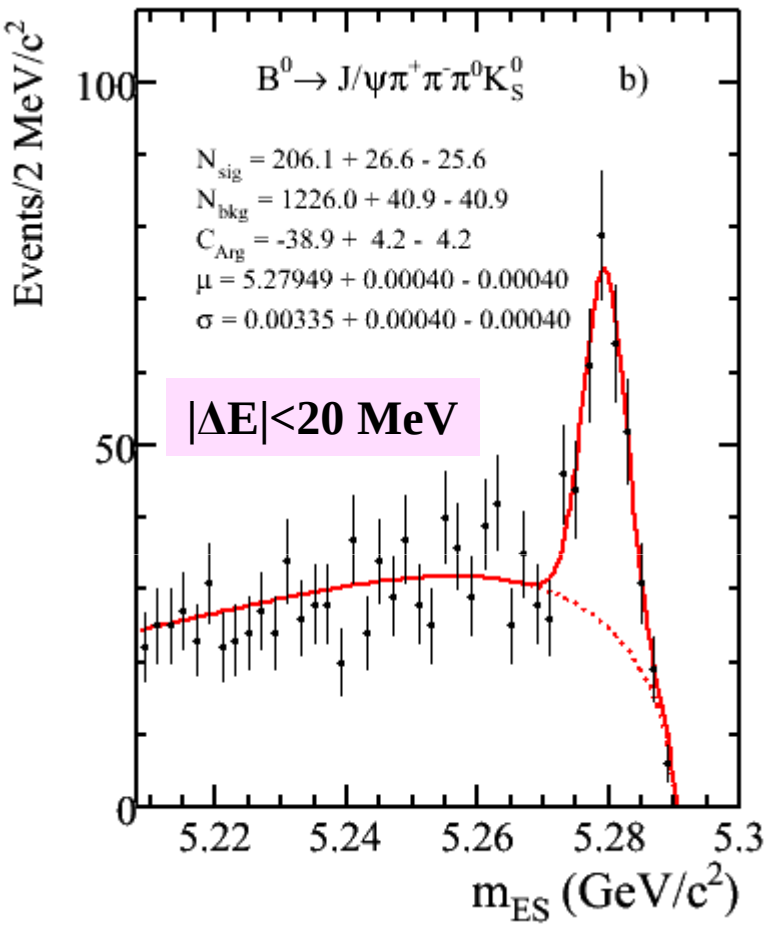
Summary

- *BABAR* searched for ξ(2230) using the full dataset; No evidence for ξ(2230) →KK has been found
- *BABAR* *updated* the Y(3940) parameters (mass, width, & BF's)
- *BABAR* reported an *evidence* for the decay mode *X(3872)→J/ψω* (4.0σ significance)
- The *P-wave* hypothesis for the X(3872) decay describes the data better than the S-wave
- ➔ X(3872) is more *likely* to have $J^P=2^-$ than $J^P=1^+$ state ➔ consistent with charmonium $\eta_{c2}(1D)$ interpretation

Backup slides

Fitting m_{ES} with new $m_{3\pi}$ window



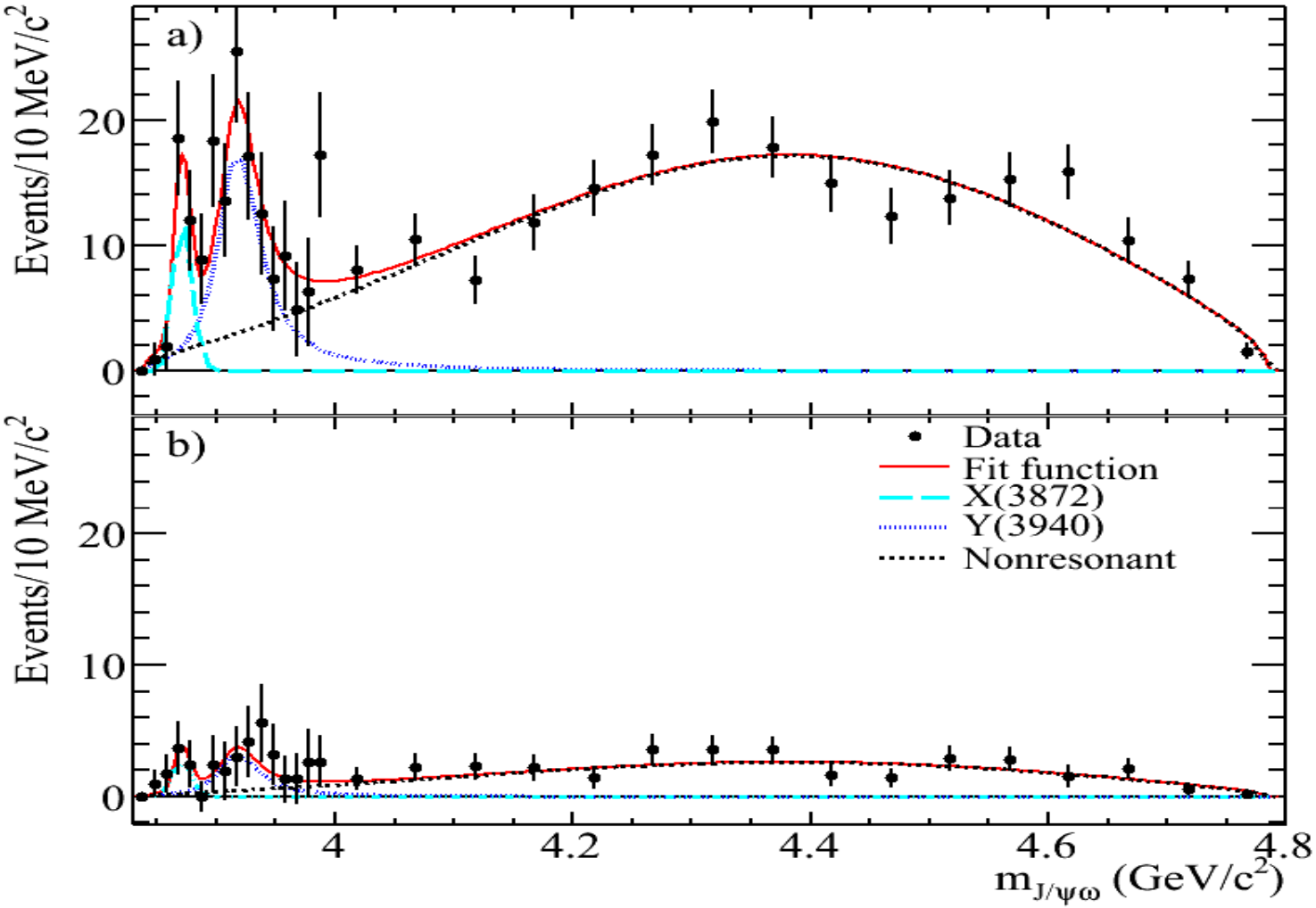


Clear m_{ES} signals in both B^+ and B^0 with ~1160 and ~210 signal events, respectively

Selection Criteria

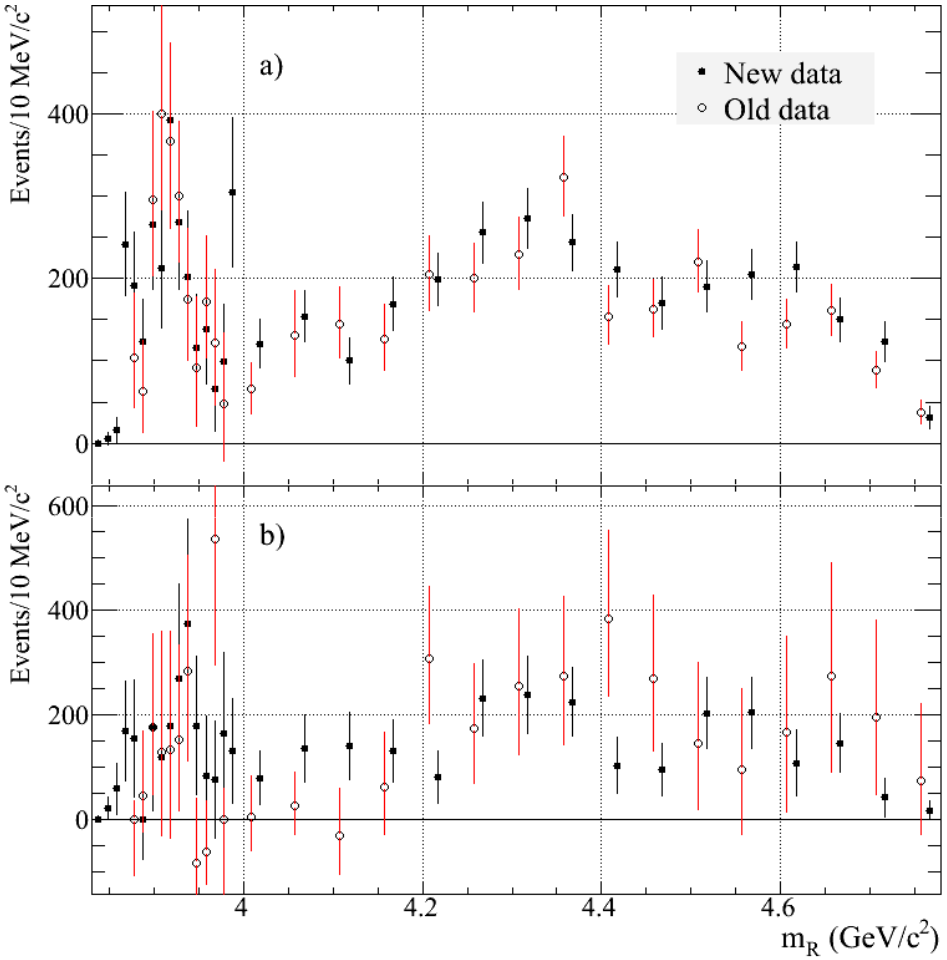
Selection Category	Criterion
$J/\psi \to \mu\mu$ mass (GeV/c^2)	$3.06 < m_{\mu\mu} < 3.14$
$J/\psi \to ee$ mass (GeV/c^2)	$2.95 < m_{ee} < 3.14$
π^0 mass (GeV/c^2)	$0.115 < m_{\gamma\gamma} < 0.150$
ΔE (GeV)	$\lvert \Delta E \rvert < 0.015$ (B^+); $\lvert \Delta E \rvert < 0.020$ (B^0)
B-helicity angle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

Fitting the UNCORRECTED Data

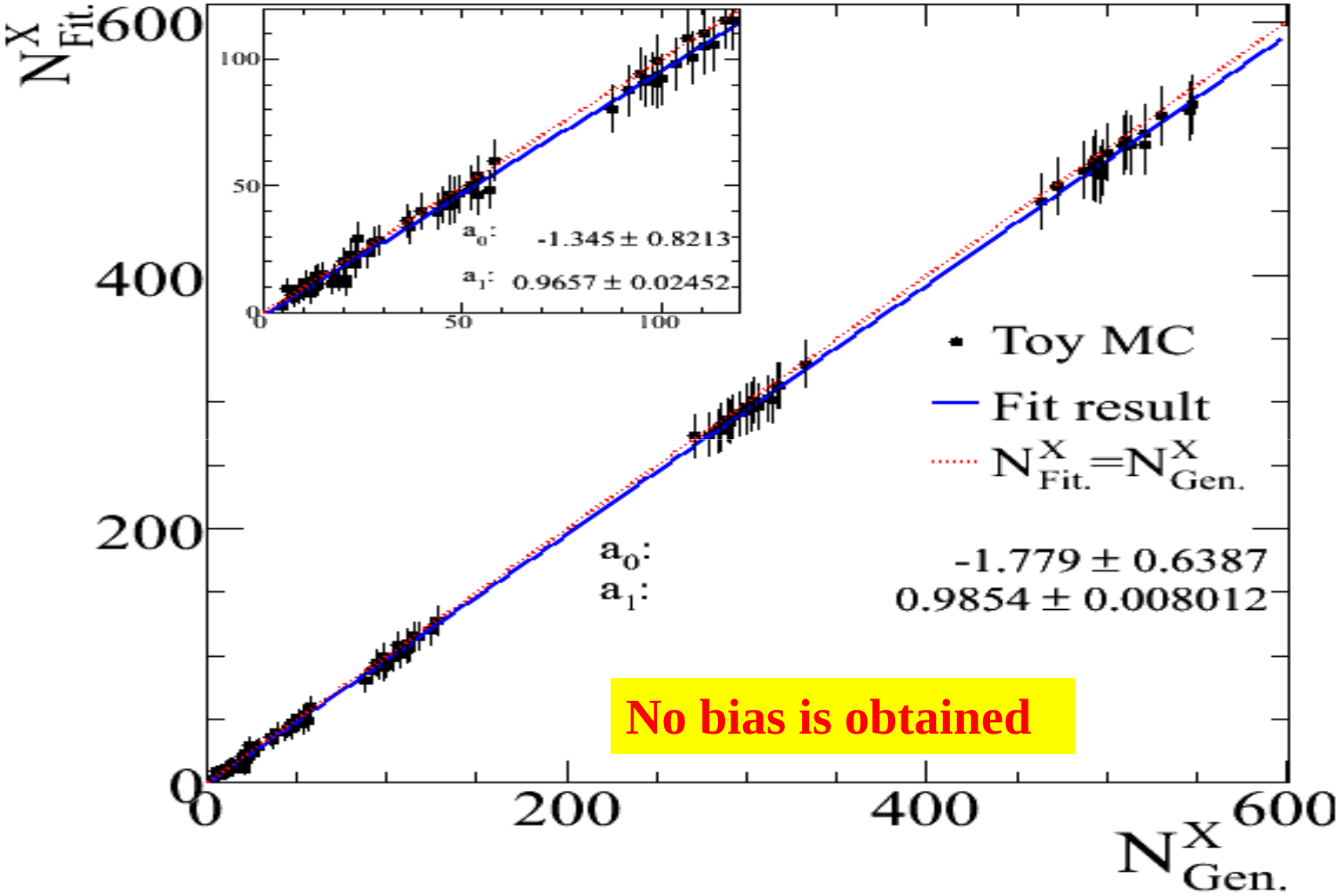


Parameter values (other than normalizations) are consistent with fits to corrected data

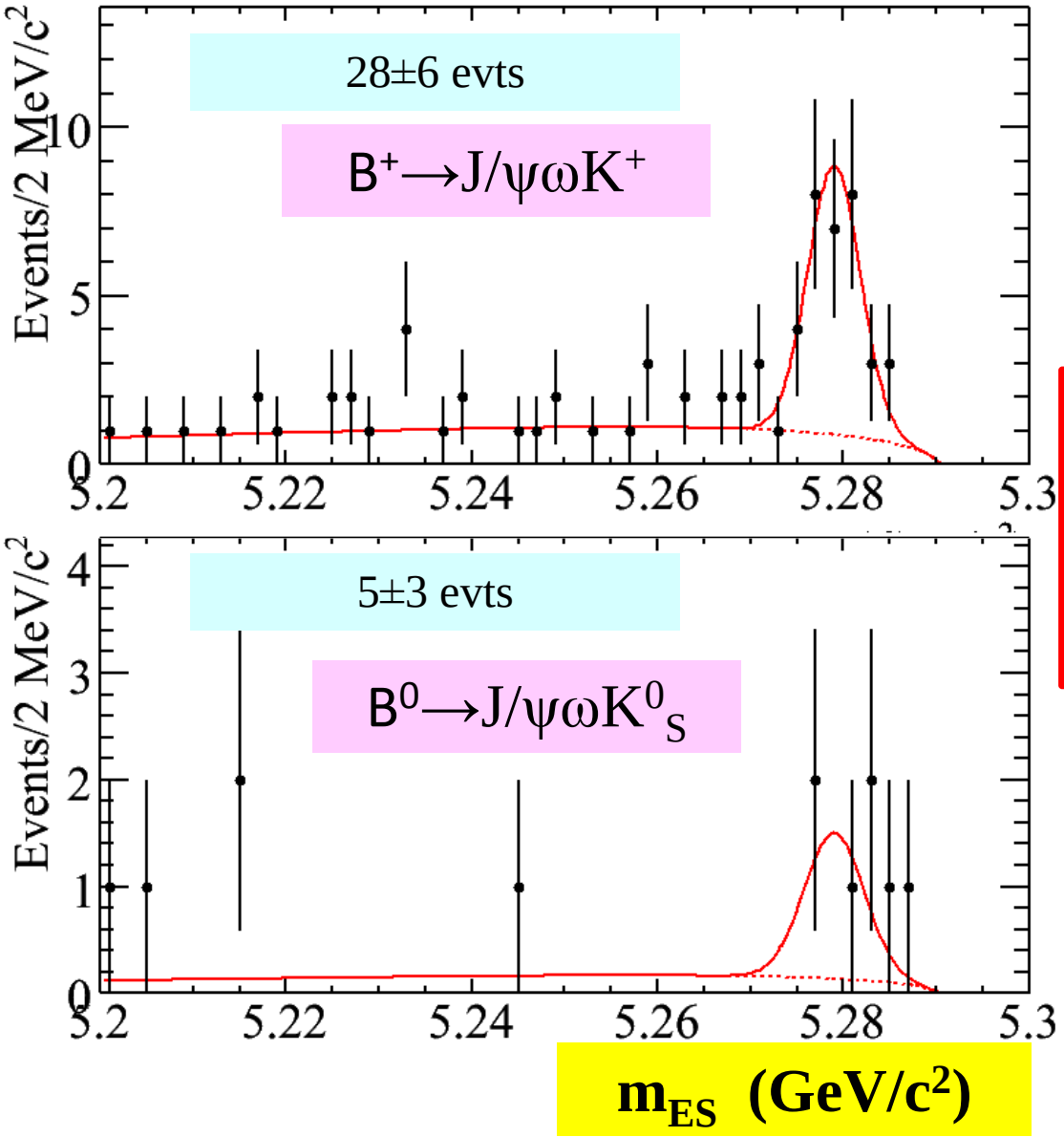
Comparison: Old and New Analysis



Bias in the Fitting Procedure?



Events Around the X(3872)



Events in

$3.8625 < m_{J/\psi\omega} < 3.8825$ GeV/c^2

Systematic Uncertainties

- Embedding X(3872) signal in background Toys
- Tracking, PID, Neutral Efficiencies, and B-Counting
- Secondary Branching Fractions
- Uncertainties in the m_{ES} Shape parameter values
- Fitting the Uncorrected Data
- P-wave BW Vs. S-wave BW for the Y(3940)

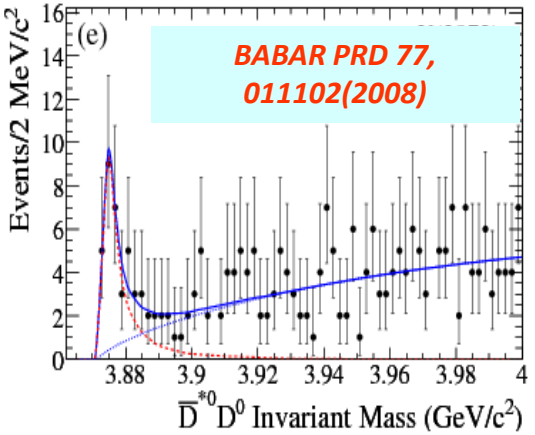
$B \to XK,\ X \to D^0 \bar{D}^{*0}$

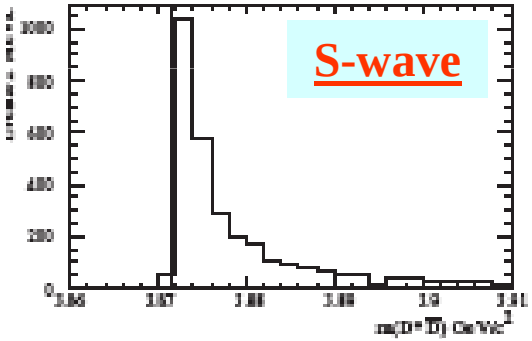
- Both *BABAR* and Belle reported a shift in X(3872) mass in the decay mode $X \to D^0\bar{D}^{*0}$(~3875 MeV/c^2) (*No shift* in mass in the most recent analysis from Belle)

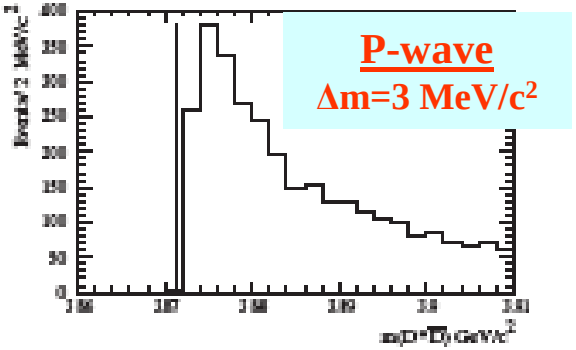
From *BABAR* and CDF: $\Delta m = 3.5 \pm 0.8$ MeV/c^2

- The shift in $D^0\bar{D}^{*0}$ mass may be due to one unit of orbital angular momentum, as for the ω

- An explanation of the shift for $X(3872) \to D^0\bar{D}^{*0}$ can be found in *PRL 100, 062006 (2008)*







The X(3872)→ψ(2S)γ

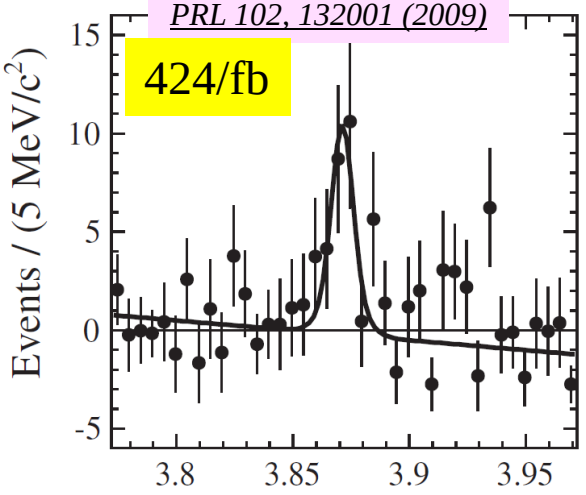
- *BABAR* also reports evidence of *X(3872)→ψ(2S)γ in* $B^+ \to X(3872)K^+$ *at* 3.5σ
- $B \to \psi(2S)(K\pi)$ *background is included in MC study*

$$\frac{\mathcal{B}(X(3872)\to\psi(2S)\gamma)}{\mathcal{B}(X(3872)\to J/\psi\gamma)} = 3.4 \pm 1.4$$

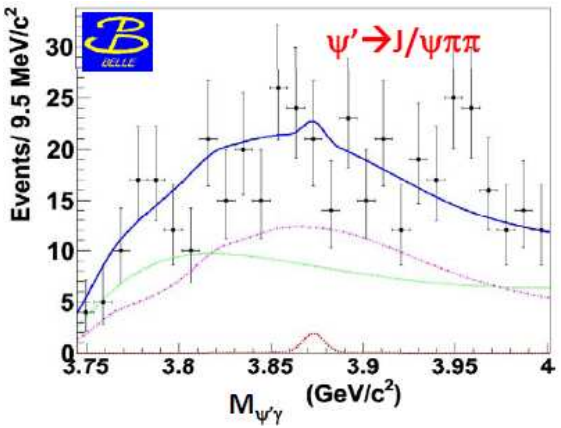
- **Belle** does **not confirm** the existence of the decay mode **X(3872)→γψ(2S)**
- When remove the background due to B→ψ(2S)K*(892), K*(892)→Kπ0, the ψ(2S)γ mass does not show any peak at the X(3872) resonance
- Belle's upper limit:

$$\frac{\mathcal{B}(X(3872)\to\psi(2S)\gamma)}{\mathcal{B}(X(3872)\to J/\psi\gamma)} \quad <2.1 \text{ @ 90\% C.L.}$$

BABAR
PRL 102, 132001 (2009)



Belle Preliminary 850/fb



The *BABAR* X(3872)→ψ(2S)γ

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)