Evidence for X(3872)→J/ψω

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Introduction

- X(3872): first new charmonium-like state discovered at the B-factories by Belle in $B \rightarrow XK$, $X \rightarrow J/\psi\pi^+\pi^-$

- Confirmation from: CDF, D0, & *BABAR*

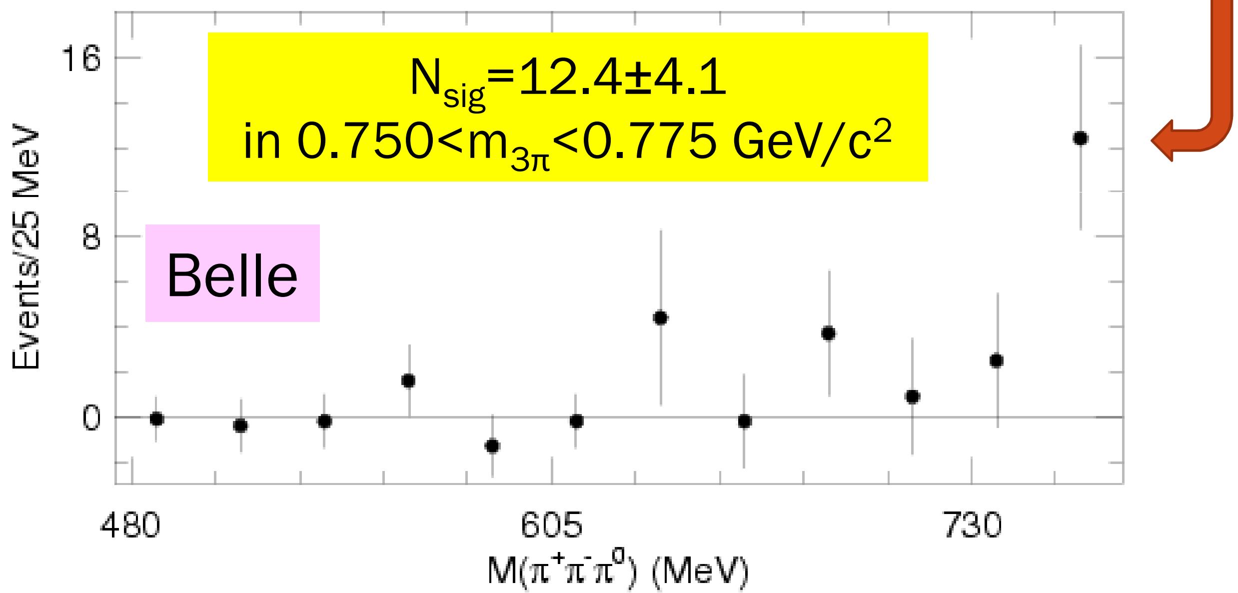
- So far, the X is the only new charmonium-like state observed with more than one decay mode: $X \rightarrow J/\psi\gamma$, $X \rightarrow \psi(2S)\gamma$, and $X \rightarrow D^0\overline{D}^{0*}$ and $J/\psi\pi^+\pi^-$ (assuming different X, Y, Z states)

- The decay modes: $X \rightarrow J/\psi\gamma$, $X \rightarrow \psi(2S)\gamma$ ➔ C=+1
- No charged partner for the X ➔ I=0

- J^P for the X was studied by Belle & CDF using $X \rightarrow J/\psi\pi^+\pi^-$; CDF showed that couldn't distinguish between 1^+ and 2^-

Introduction (cont.)

- In hep-ex/0505037, Belle reported an excess of events in $m_{3\pi}$ above 750 MeV/c^2 in the decay $B \to J/\psi 3\pi K$ for $|m_{J/\psi 3\pi} - 3872| < 16.5$ MeV/c^2 and interpreted as $X \to J/\psi\omega$



- In *BABAR*, we search for the decay mode $X \to J/\psi\omega$ in the decays $B \to J/\psi\omega K$, $\omega \to \pi^+\pi^-\pi^0$

BABAR Previous Analysis

PRL 101, 082001 (2008)

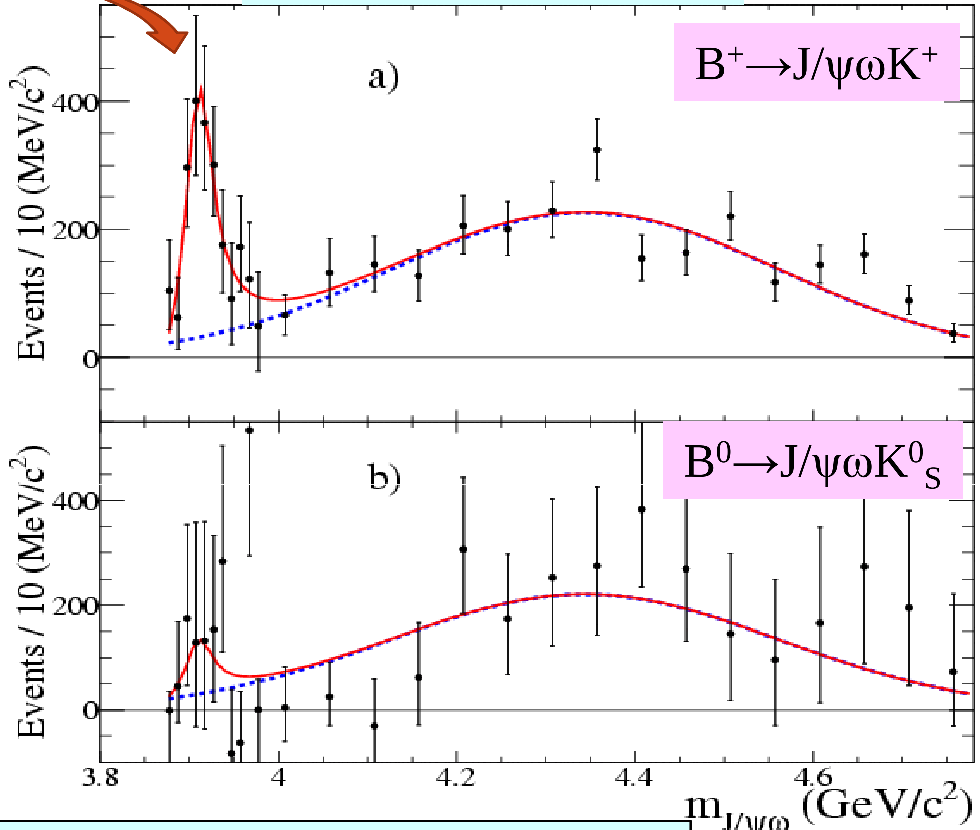
Y(3940)!

$m=3914.6_{-3.4}^{+3.8}(stat)\pm2.0(syst)$ MeV/c^2

$\Gamma=34_{-8}^{+12}(stat)\pm5(syst)$ MeV

Product B.F.(B+)=
$[4.9_{-0.9}^{+1.0}(stat)\pm0.5(syst)]\times10^{-5}$

Product B.F.(B0)=
$[1.3_{-1.1}^{+1.3}(stat)\pm0.2(syst)]\times10^{-5}$



With $0.7695< m_{3\pi}<0.7965$ (B^+) as obtained from optimization

No evidence for X with this definition of the ω signal region, although MC simulation with S-wave J/ψω system indicated that we could have seen it

The method

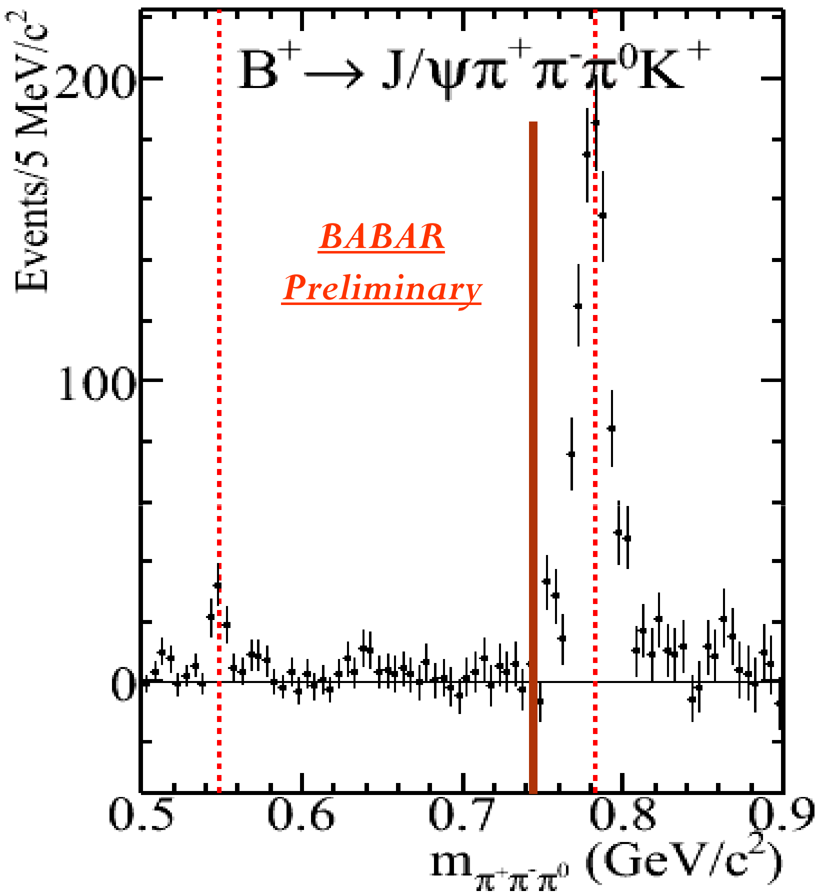
- We use the same selection criteria used in the previous *B*A*B*AR analysis (*PRL 101, 082001*), except that on the lower-mass limit of the ω signal region

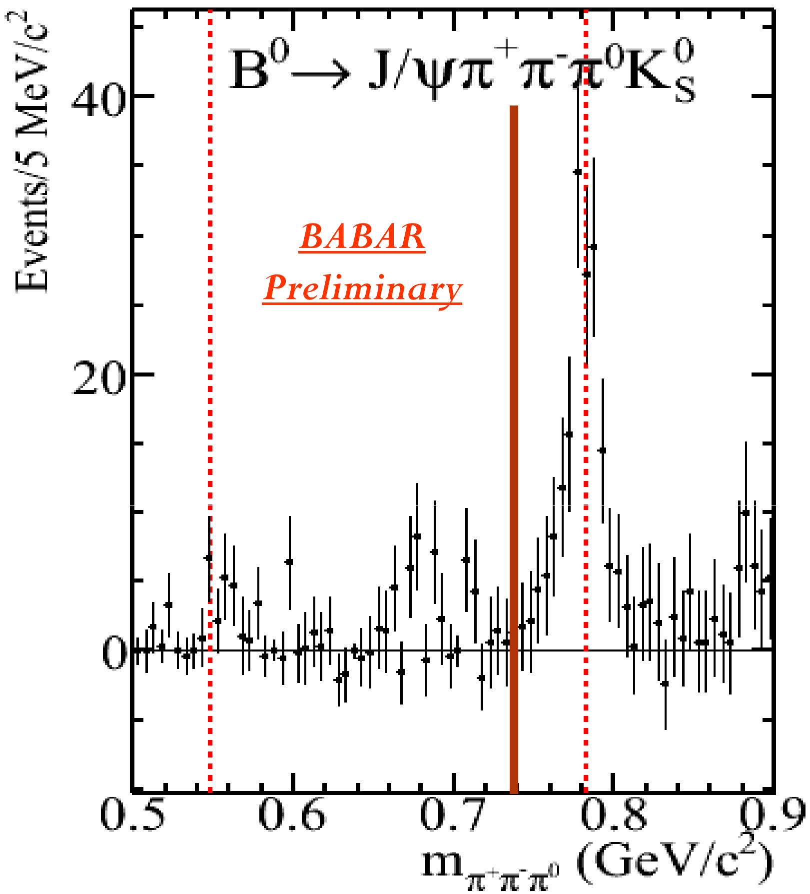
- Fit m_{ES} in intervals of variable of interest to extract the B-related signal (after ΔE requirement)

- 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 $m_{J/\psi\omega}$

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

$m_{3\pi}$ Distributions





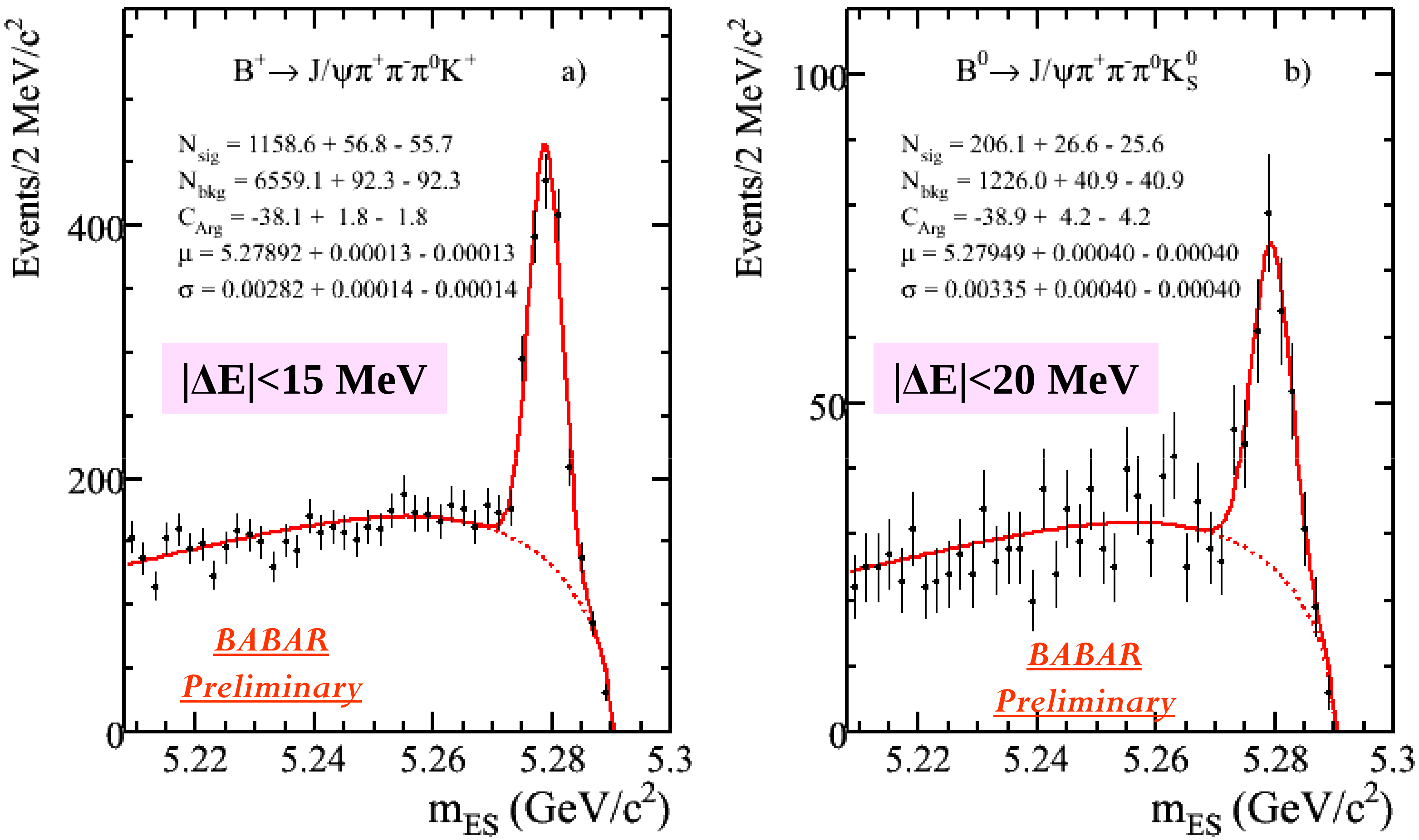
Clear η and ω signals!; Negligible background

➔ Modify the *lower-mass limit* of the ω region to be *0.740 GeV/c^2*

Different Ranges of $m_{3\pi}$

Criterion (GeV/c^2)	
$0.7695 < m_{3\pi} < 0.7965$ (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)	

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



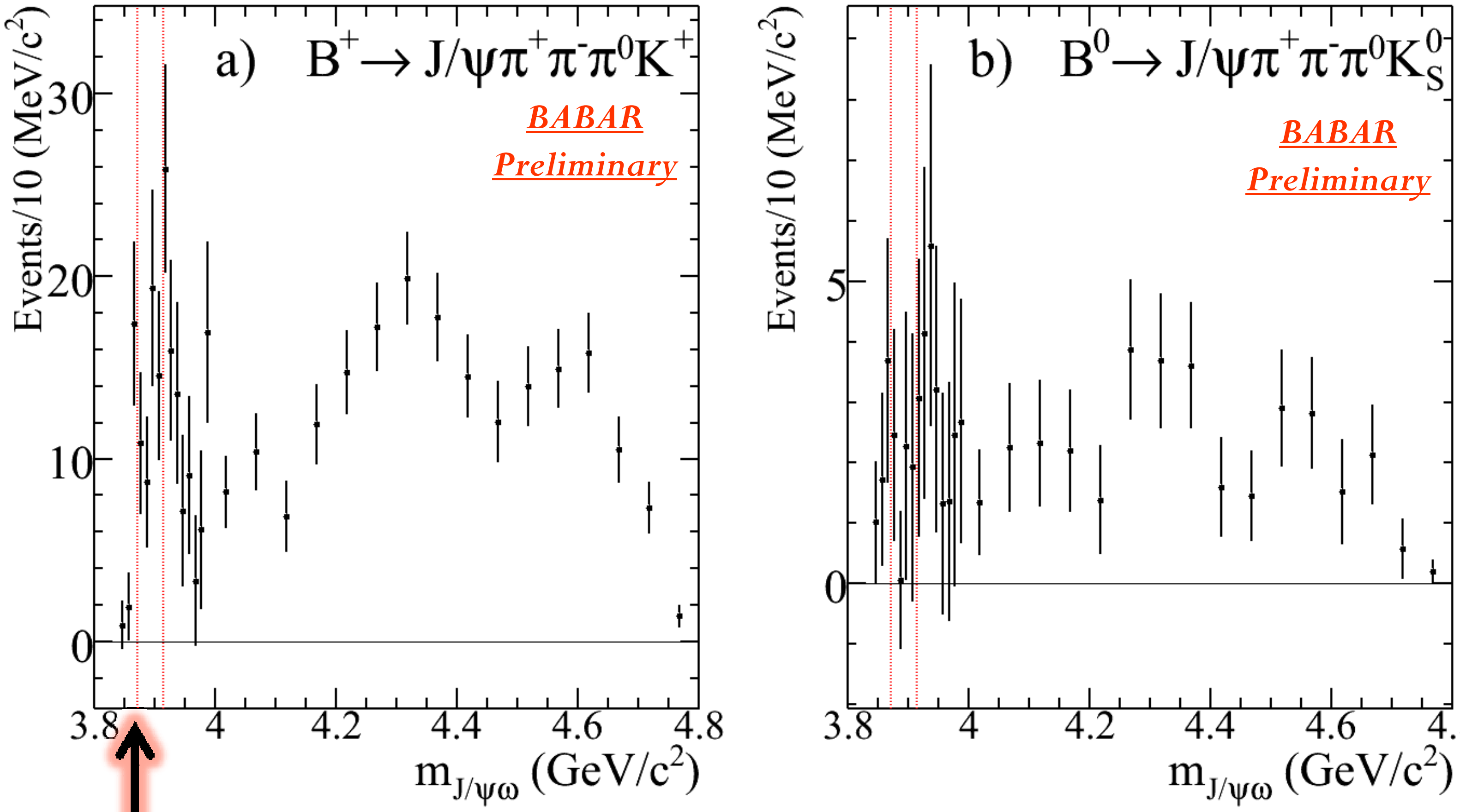
Clear m_{ES} signals in both B^+ and B^0 with ~1160 and ~210 signal events, respectively

$m_{J/\psi\omega}$ Dependence of:

- Efficiency:
  - For B^+ (B^0), 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/c^2

- Mass resolution:
  - The resolution changes gradually from 6.5 MeV/c^2 at 3.84 GeV/c^2, to 9 MeV/c^2 at 4.8 GeV/c^2

m_{ES} Fits in $m_{J/\psi\omega}$ Intervals



New feature; X(3872)!

B^+ and B^0 simultaneous Fit

$$\frac{dN^+}{dm_{J/\psi\omega}} = n_X^+ Gauss + n_Y^+ BW(Y) + n_{bkg}^+ BKG$$

$$\frac{dN^0}{dm_{J/\psi\omega}} = n_X^0 Gauss + n_Y^0 BW(Y) + n_{bkg}^0 BKG$$

$$\frac{dN^+}{dm_{J/\psi\omega}} = n_X^+ Gauss + n_Y^+ BW(Y) + n_{bkg}^+ BKG$$

$$\frac{dN^0}{dm_{J/\psi\omega}} = R_X n_X^+ Gauss + R_Y n_Y^+ BW(Y) + R_{bkg} n_{bkg}^+ BKG$$

Repeat fit to extract values of $R = B^0_{rate} / B^+_{rate}$

Where

Gauss : Gaussian function for the X(3872)

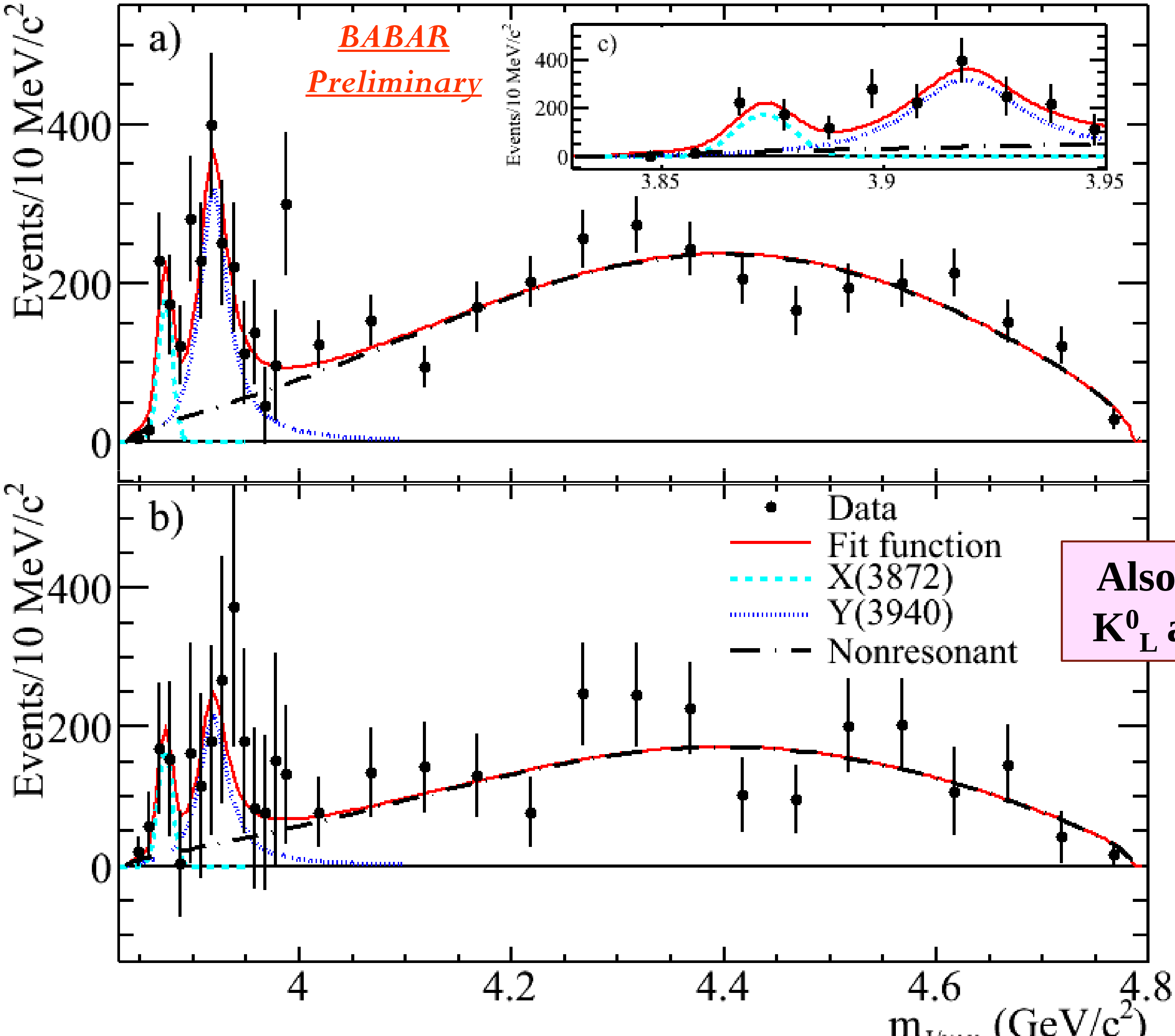
BW(Y): Breit-Wigner function for the Y(3940) × phase space

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

There are 11 parameters in the fits:

n_X, n_Y, n_{bkg}, R_X, R_Y, R_{bkg}, m_X, m_Y, Γ_Y, μ_{bkg}, σ_{bkg}

Fitting the efficiency CORRECTED Data



Also corrected for K^0_L and $K^0_S \rightarrow \pi^0\pi^0$

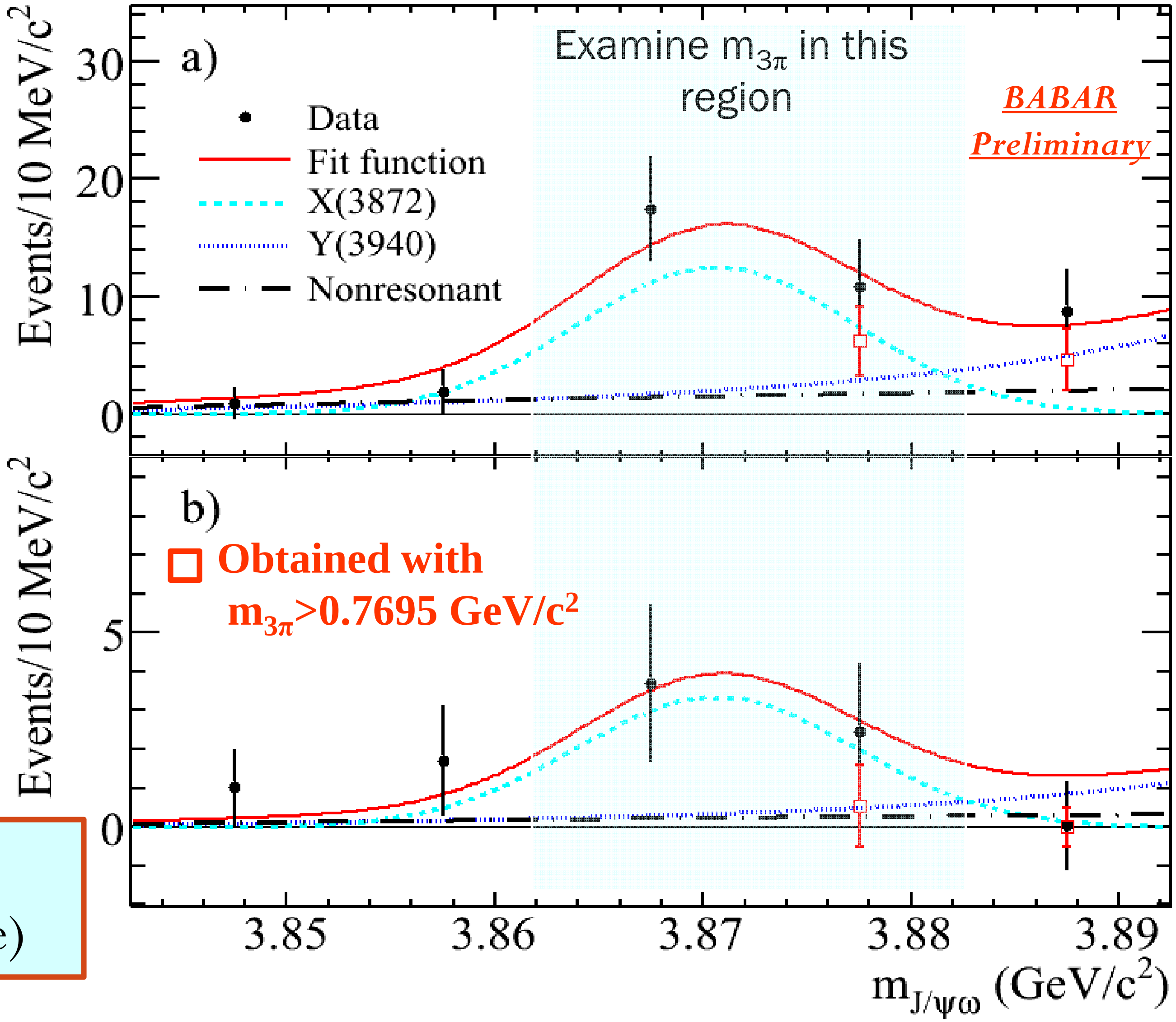
Fit Results

BABAR Preliminary

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)

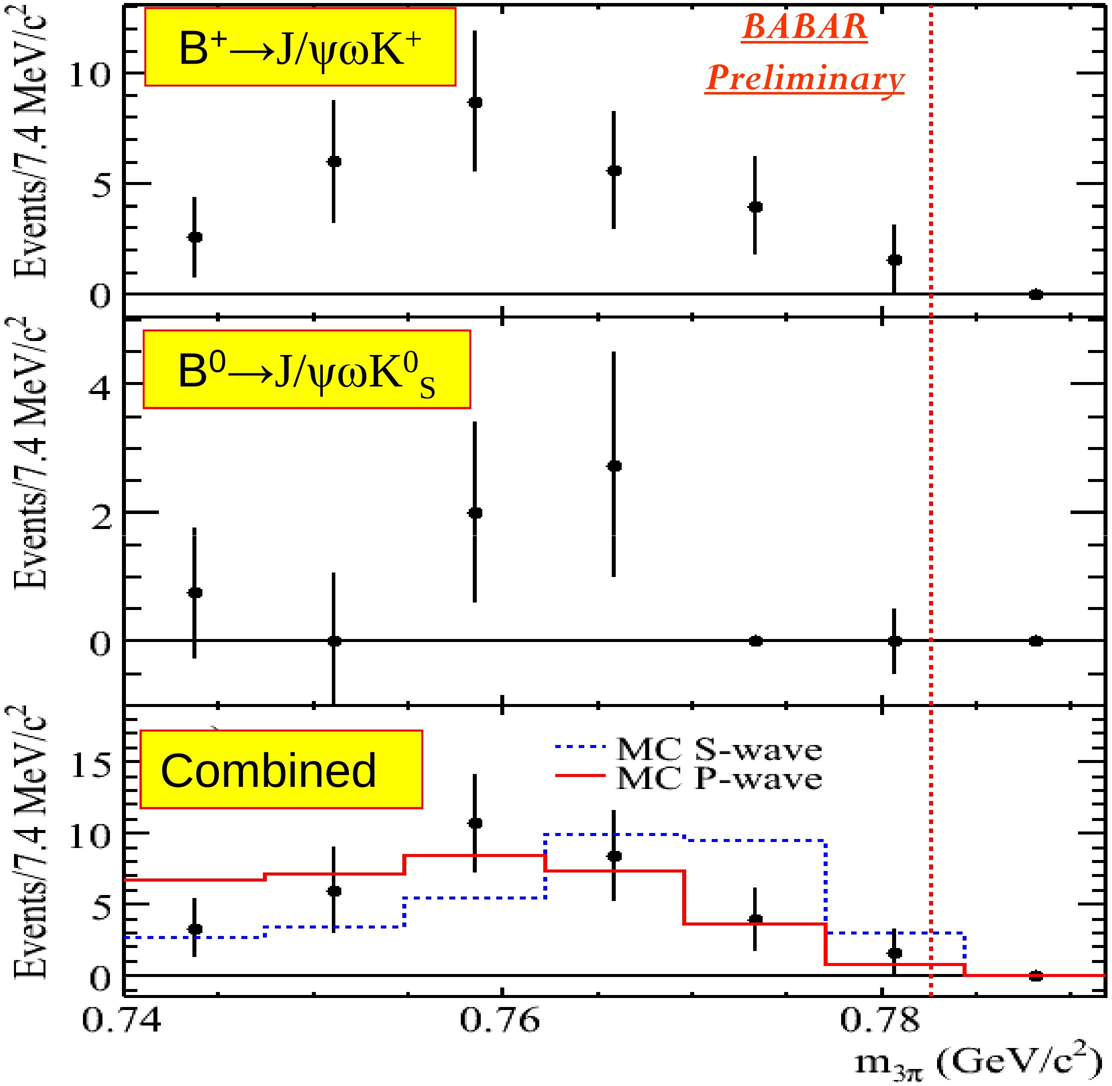
Uncorrected data in the X(3872) region

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



3.5σ signal size
(4.0σ significance)

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



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%

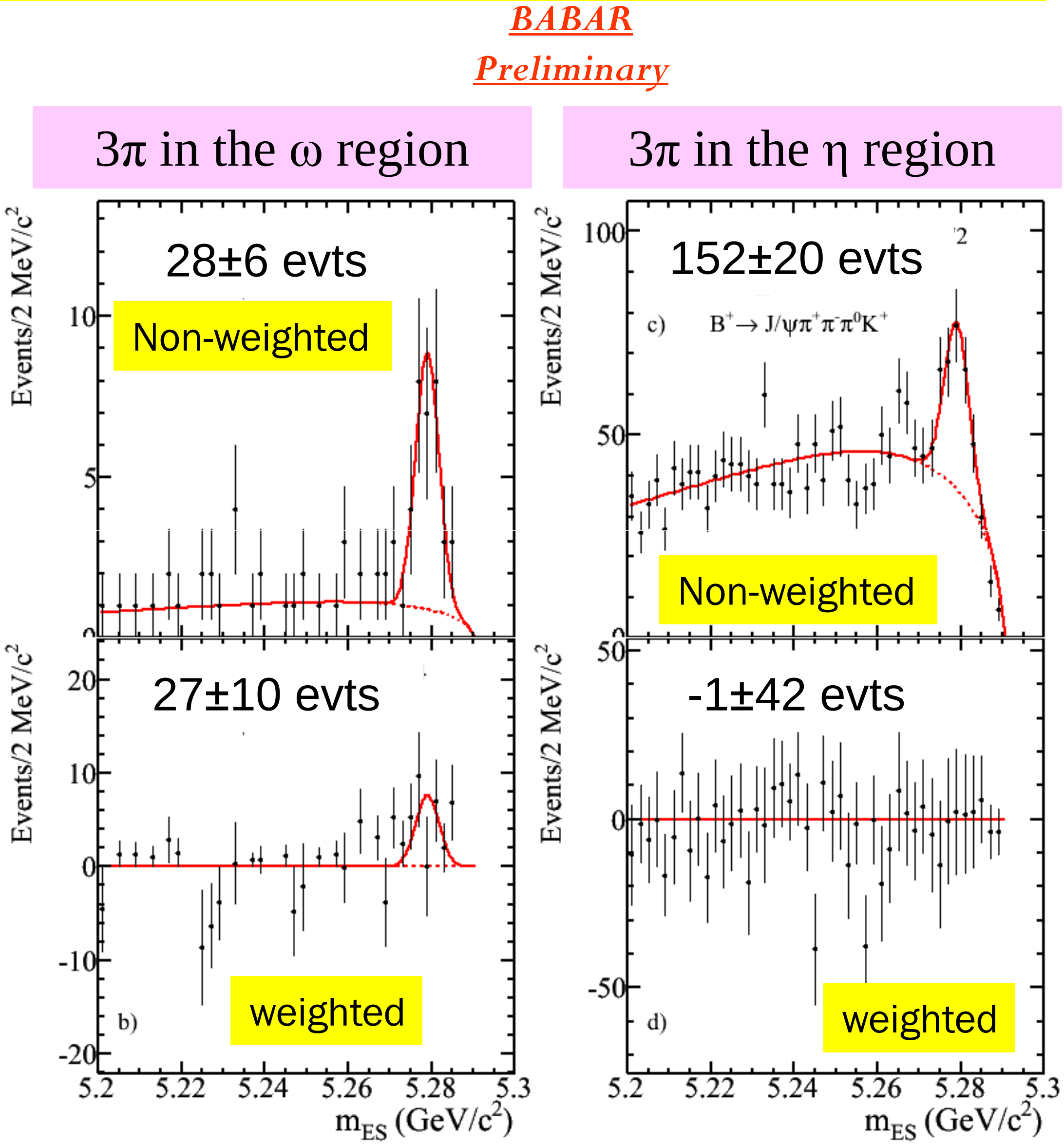
➔ Negative Parity favored

How do we justify calling such a distribution ω signal?

Daltiz-Plot weighting technique

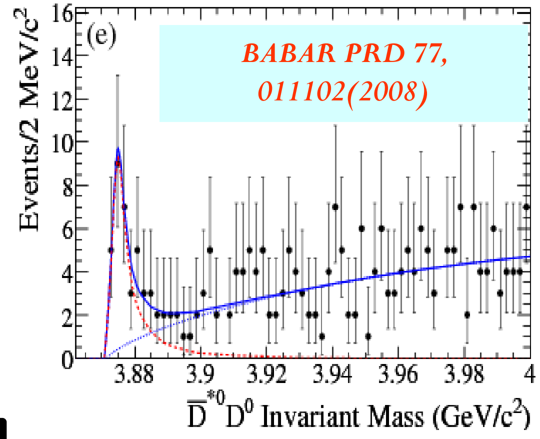
Each event is given weight of (5/2)(1-$3\cos^2\theta_h$), where θ_h is the angle between the π^+ and π^0 in the $\pi^+\pi^-$ rest frame

Non-ω events projected away



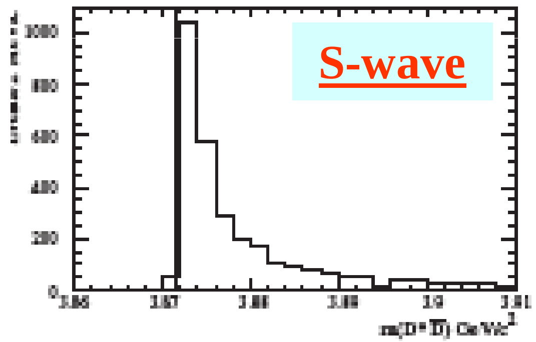
$B \to XK,\ X \to D^0 \bar{D}^{*0}$

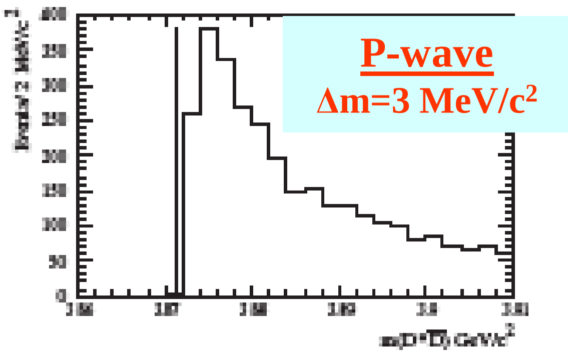
- Both *B*A*B*AR and Belle reported a shift in X(3872) mass in the decay mode $X \to D^0\bar{D}^{*0}$(~3875 MeV/c²) (*No shift* in mass in the most recent analysis from Belle)



From *B*A*B*AR and CDF: $\Delta m = 3.5 \pm 0.8$ MeV/c²

- 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)*

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)

Branching Fractions

BABAR Preliminary

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

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

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

***BABAR average:* 0.8 ± 0.3**

Belle: $1.0 \pm 0.4 \pm 0.3$

Summary

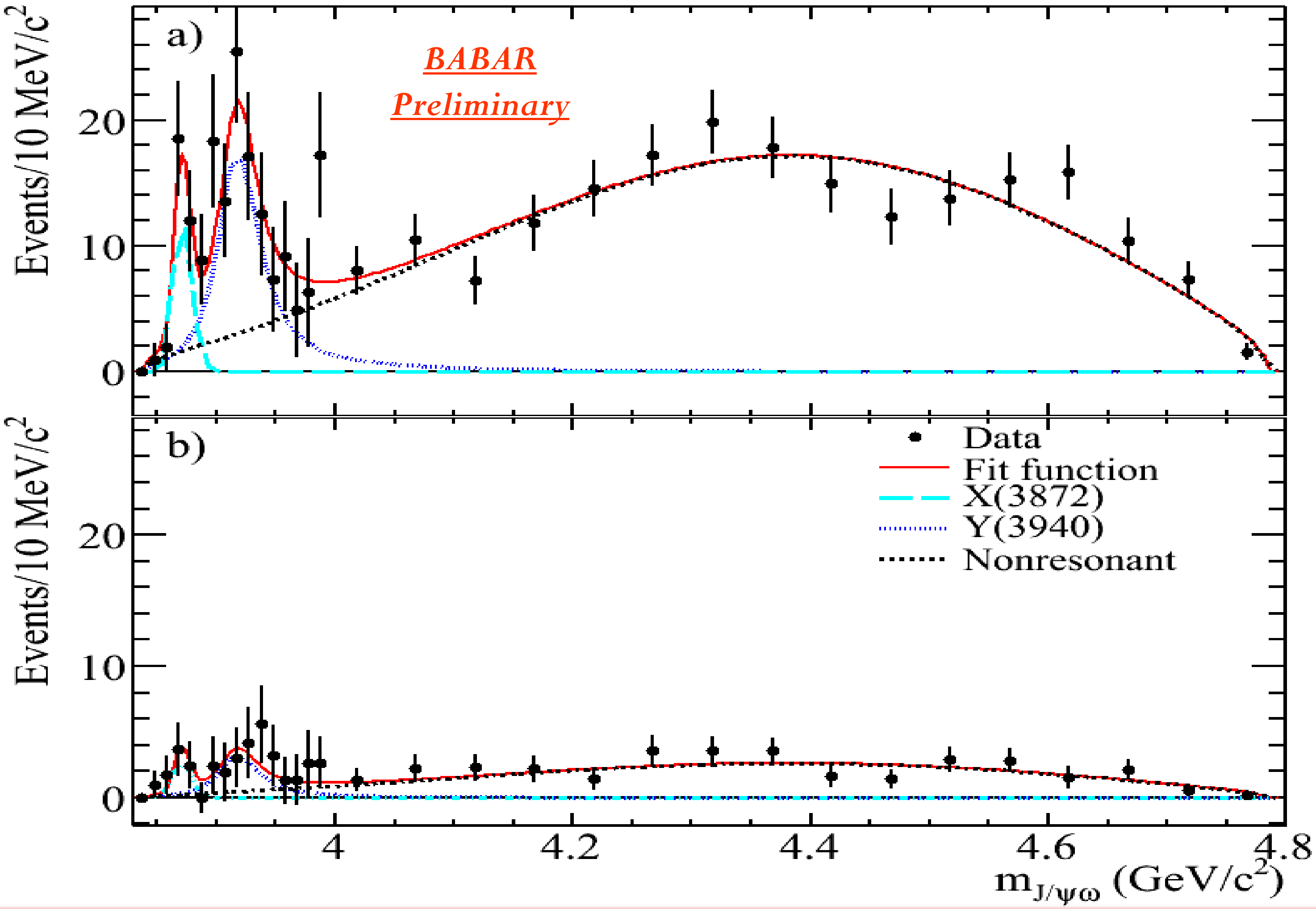
- We have *updated* our parameter values for the *Y(3940)*
- We report *evidence* for the decay mode *$X(3872) \rightarrow J/\psi\omega$* (~3.5σ signal size; 4.0σ significance)
- The *P-wave* hypothesis for the X(3872) decay describes the data better than the S-wave
- ➔ X(3872) is more *likely* to have *$J^P=2^-$* than $J^P=1^+$ state ➔ consistent with charmonium $\eta_{c2}(1D)$ interpretation

Backup slides

Selection Criteria

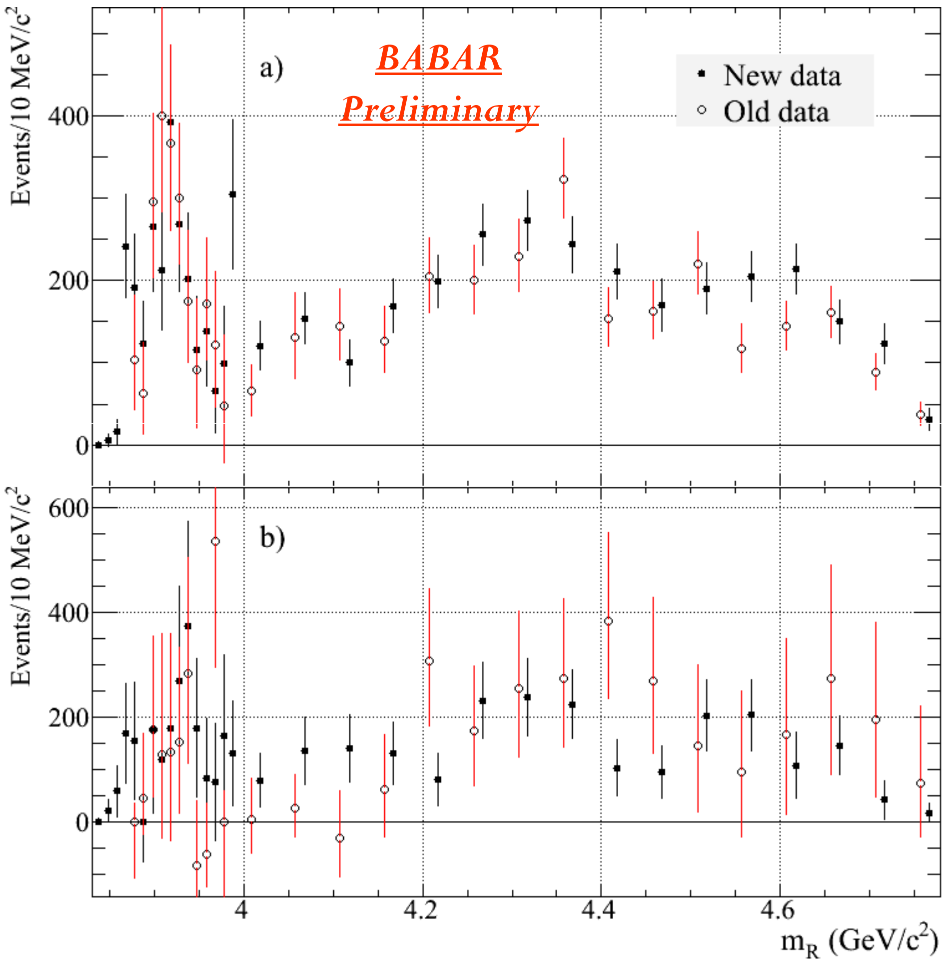
Selection Category	Criterion
$J/\psi \to \mu\mu$ mass (GeV/c^2)	$3.06 < m_{\mu\mu} < 3.14$
$J/\psi \to ee$ mass (GeV/c^2)	$2.95 < m_{ee} < 3.14$
π^0 mass (GeV/c^2)	$0.115 < m_{\gamma\gamma} < 0.150$
ΔE (GeV)	$\lvert\Delta E\rvert < 0.015$ (B^+); $\lvert\Delta E\rvert < 0.020$ (B^0)
B-helicity angle	$\lvert\cos\theta_B\rvert < 0.9$
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

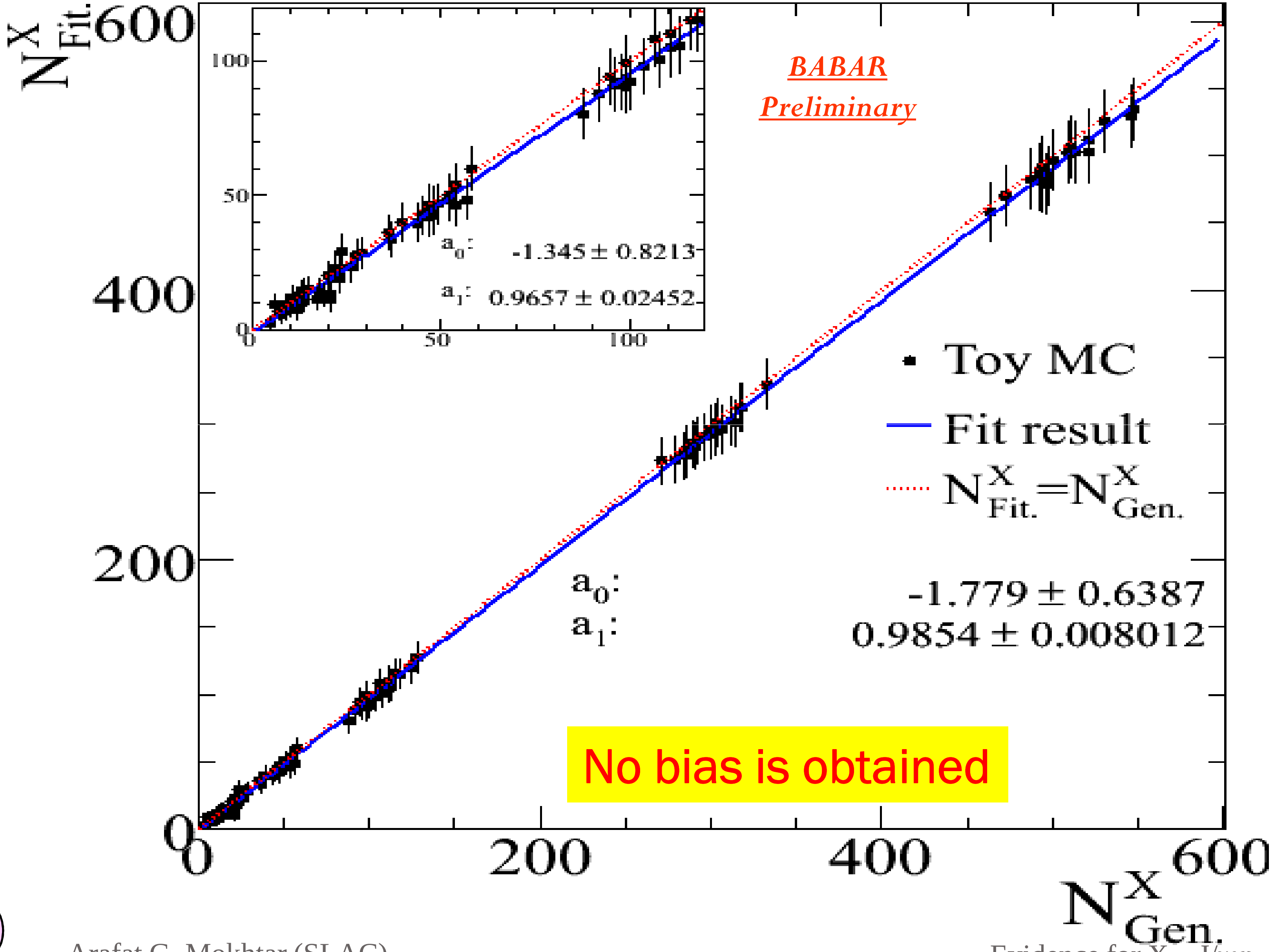


Parameter values (other than normalizations) are consistent with fits to corrected data

Comparison: Old and New Analysis

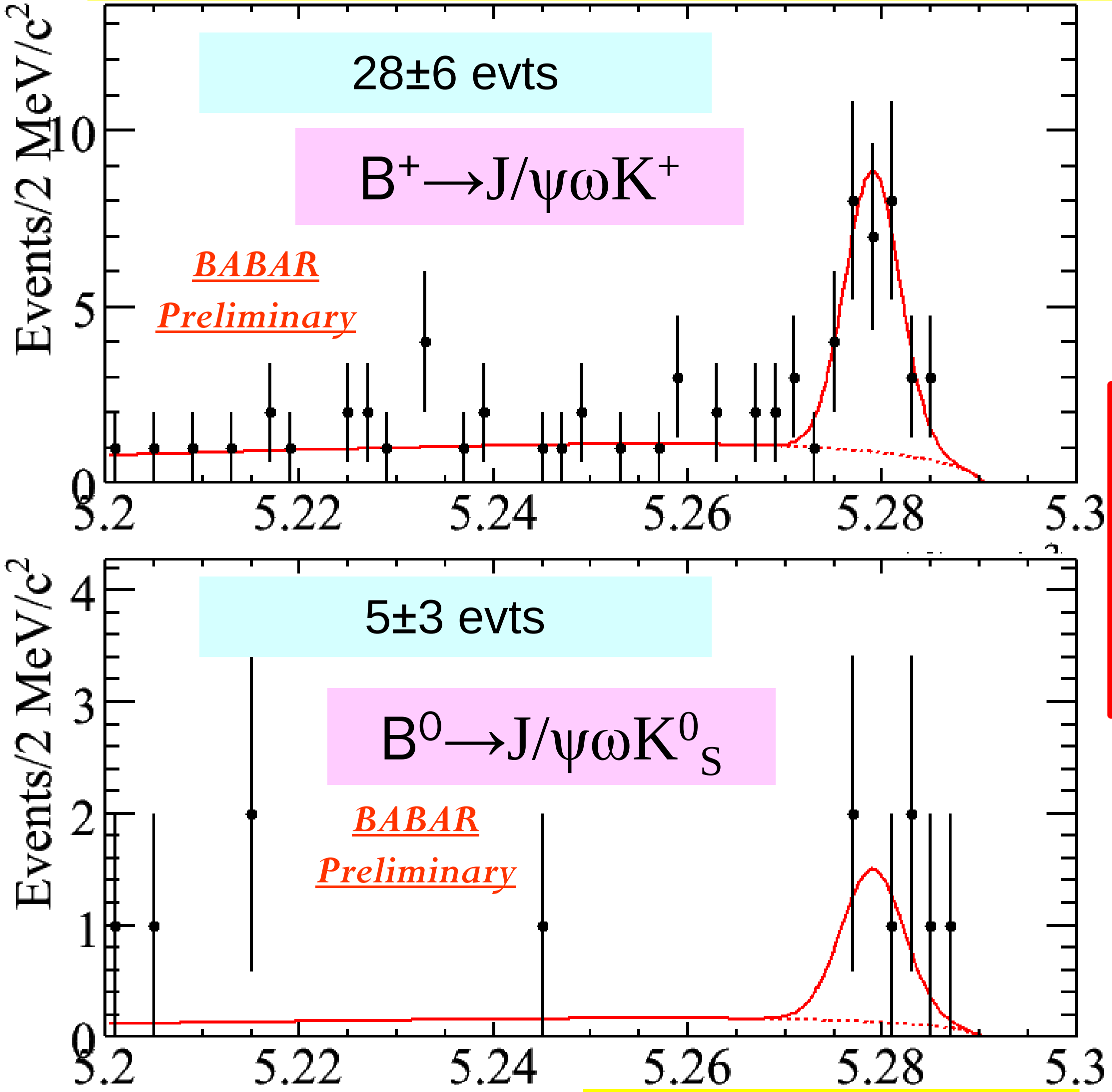


Bias in the fitting procedure?



No bias is obtained

Events around the X(3872)



m_{ES} (GeV/c^2)

Events in

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

Results-I: Fit Parameters

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