Charmonium and X, Y at Belle

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- X(3872)
  - mass & width determination, BR $J/\psi\pi^+\pi^-$ mode
  - angular analysis
  - radiative decays
- Y(4260)
  - search in $J/\psi\pi^0\pi^0$ channel
- η_c and $\eta_c(2S)$
  - estimation of the interference effect

Introduction

B-factories provide a great opportunity to study known charmonium states and discover new ones.

Since 2002 B-factories found more than 10 states that

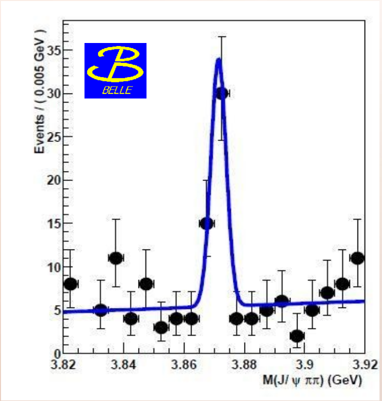
- probably contain a (c anti-c) pair ⇒ "charmonium-like" states
- have mass above the open charm threshold
- are in poor agreement with the charmonium potential model

Exotic state models:

- Multiquark state
  - Molecule (two loosely bound charm mesons)
  - Tetraquark (tightly bound four-quark state)
- Hybrid (state with excited gluonic degrees of freedom)
- Hadrocharmonium (charmonium state "coated" by light-hadron matter)
- Threshold effects
  - Virtual state at threshold
  - Charmonium state shifted by nearby $D_{(s)}^{(*)}D_{(s)}^{(*)}$ thresholds

None of these models explains all properties of observed exotic states!

X(3872)



First observed by Belle[1] in 2003 in $B \to K(J/\psi \pi^+ \pi^-)$. Mass is close to the ($D^0$anti-$D^{*0}$) threshold. Width is less than experimental resolution. Confirmed by BaBar, CDF, and D0.

Possible interpretations: → Contra:

- Charmonium state
  - $\chi_{c1}(2P)$ ⟷ large $\mathcal{B}(\chi_{c1}(2P) \to J/\psi\gamma)$ expected
  - η_{c2} ⟷ large width expected
- D^0anti-D^{*0} molecule - most popular model ⟷ unexplained production in B decays and p anti-p
- (c anti-c) and (D^0anti-D^{*0}) mixture
- Tetraquark (diquark-diantiquark) ⟷ no charged partner of X found

There are two possibilities for quantum numbers

- $M(\pi^+\pi^-)$ close to ρ decay (Belle[2] and CDF[3]) ⊕ $X(3872) \to J/\psi\gamma$ (Belle[4] and Babar[5]) established C=+1
- $X \to J/\psi \pi^+\pi^-$ (study by CDF[6]) ⇒ 1^{++} or 2^{-+}
- $X \to J/\psi\gamma$ (Belle and Babar[7]) favors 1^{++}
- $X \to J/\psi \pi^+\pi^-\pi^0$ (BaBar[8]) favors 2^{-+} (?)
- Molecular state model ⇒ 0^{-+} or 1^{++}

[1] PRL 91 261001
[2] arXiv:hepex/0505038
[3] PRL 96 102002
[4] arXiv:1105.0177
[5] PRL 102 132001
[6] PRL 98 132002
[7] arXiv:1007.4541
[8] PRD 82 011101

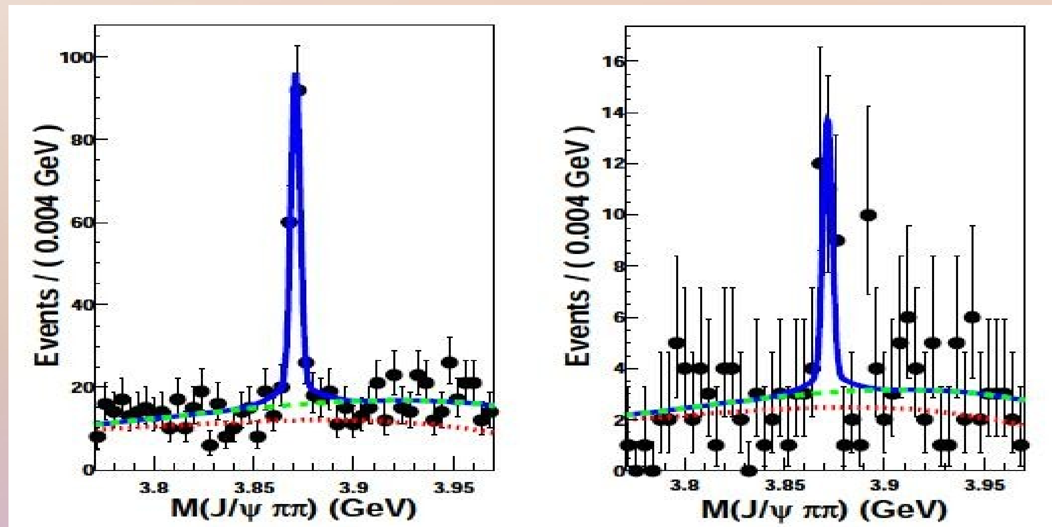
$X(3872) \to J/\psi\pi^+\pi^-$ (1)

arXiv:1107.0163

Full Belle data sample: 711 fb^{-1}

Diquark-antidiquark model predicts mass difference ΔM_X on the X mass in the two modes $B^+ \to K^+(J/\psi\pi^+\pi^-)$ and $B^0 \to K^0(J/\psi\pi^+\pi^-)$.

$B^+ \to K^+X$



$B^0 \to K_S X$

[1] PRD 77 111101(R)

$\Delta M_X = (-0.69 \pm 0.97 \pm 0.19)$ MeV

$\Delta M_X = (2.7 \pm 1.6 \pm 0.4)$ Me

is consistent with zero $\Rightarrow$ same particle.

$M_X = (3871.84 \pm 0.27 \pm 0.19)$ MeV **$\Gamma_X < 1.2$ MeV (90% CL)**

improve the previous UL on the width by a factor of 2

$B(B^+ \to K^+X) \times B(X \to J/\psi\pi^+\pi^-) = (8.61 \pm 0.82 \pm 0.52) \times 10^{-6}$

$B(B^0 \to K^0X) / B(B^+ \to K^+X) = 0.50 \pm 0.14 \pm 0.04$

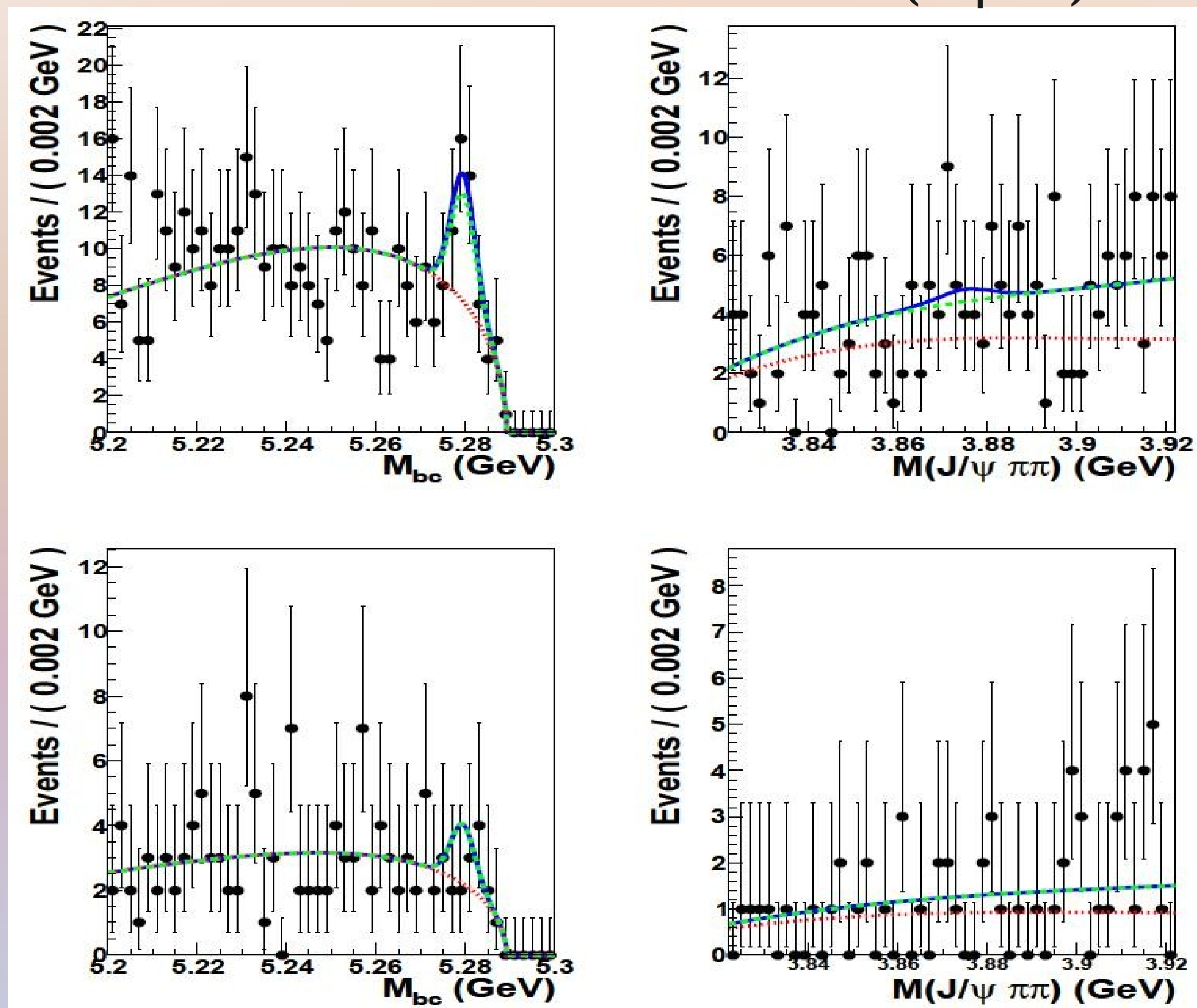
$X(3872) \to J/\psi \pi^+ \pi^0$ (2)

Singlet or triplet?

M_{bc} $M(J/\psi\pi\pi)$

$B^0 \to K^- X^+$

$B^+ \to K^0 X^+$



$\mathcal{B}(B^0 \to K^- X^+) \times \mathcal{B}(X^+ \to \rho^+ J/\psi) < 4.2 \times 10^{-6}$ $\mathcal{B}(B^+ \to K^0 X^+) \times \mathcal{B}(X^+ \to \rho^+ J/\psi) < 6.1 \times 10^{-6}$

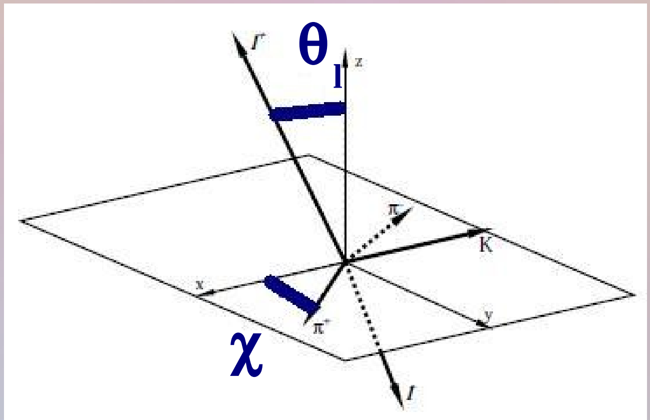
No evidence of a charged partner X^+

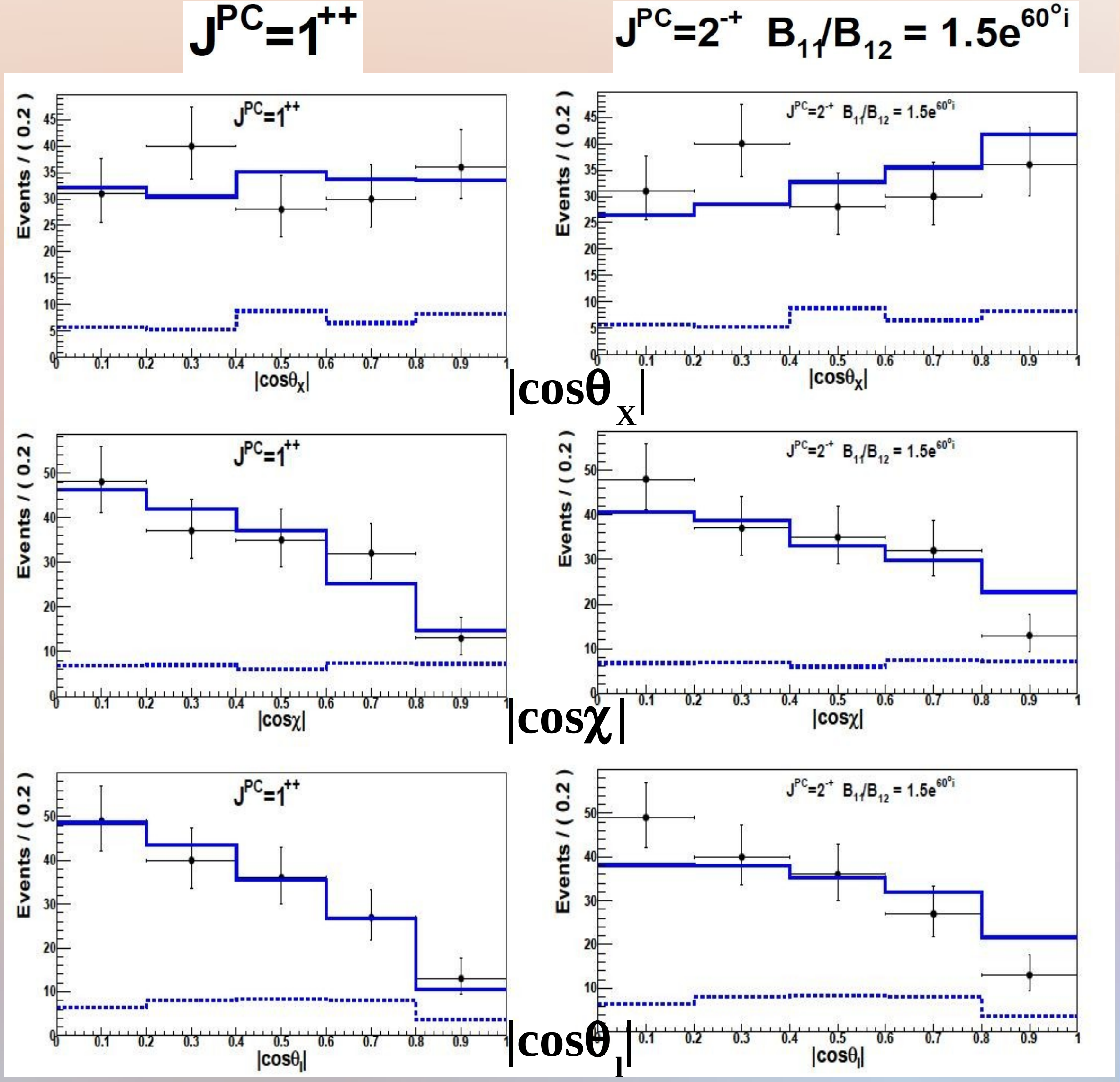
X(3872)→J/ψπ⁺π⁻ (3)

Angular correlations (θ_X*, χ, θ_l) ⇒ 1^{++} and 2^{-+} hypotheses are both possible (insufficient statistics).

ρ–J/ψ system

1^{++}	2^{-+}
S-wave	P-wave
L=0, S=1	L=1, S=1 (B_{11})
	L=1, S=2 (B_{12})





* b/w J/ψ and direction opposite to K in X restframe

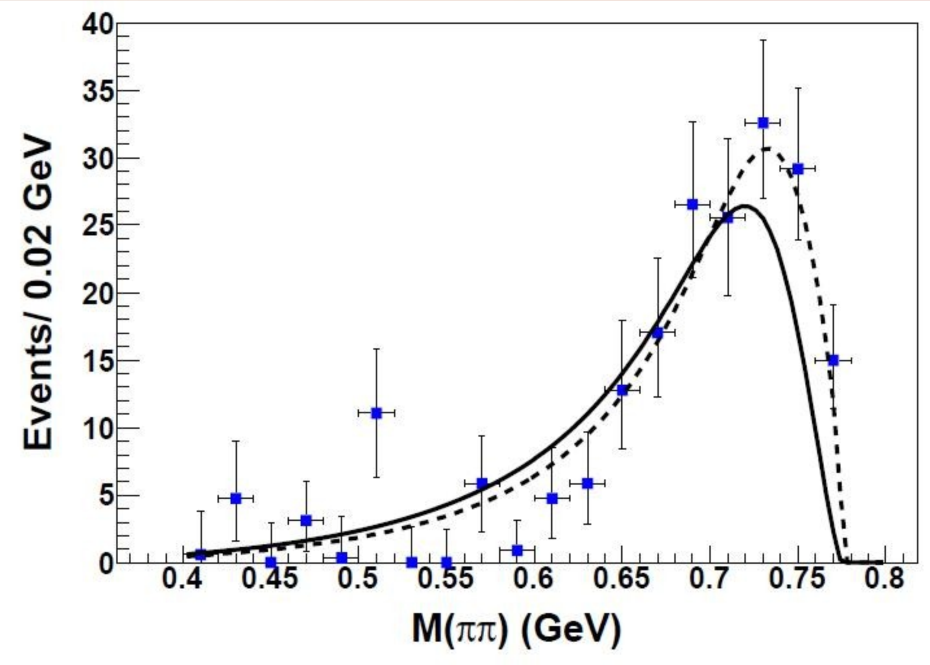
unbinned likelihood fit

$X(3872) \to J/\psi\pi^+\pi^-$ (4)

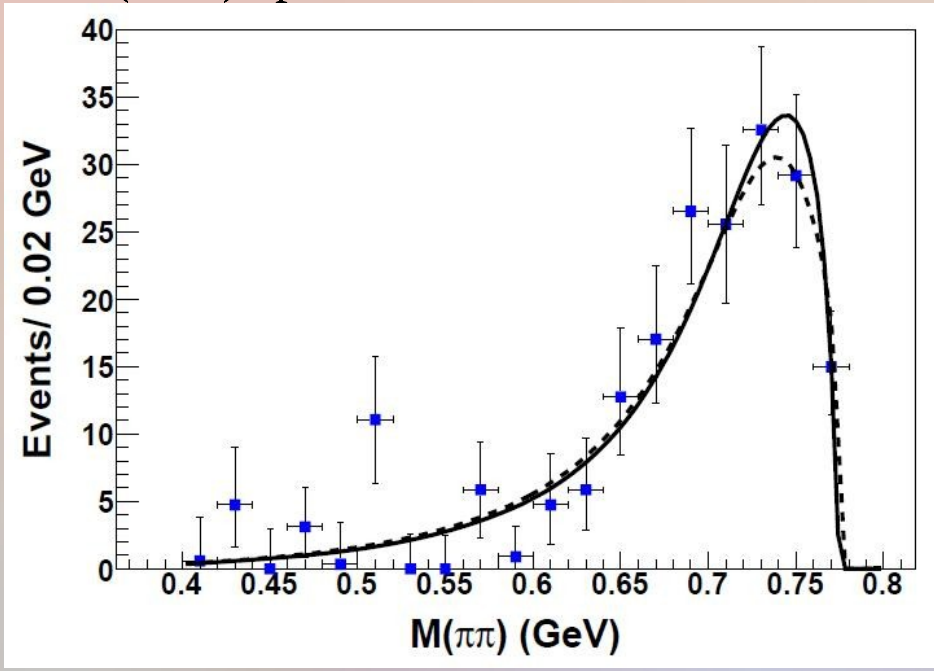
Fits to $M(\pi^+\pi^-)$ distribution taking $\rho-\omega$ interference into account

$\Rightarrow$ 1^{++} and 2^{-+} hypotheses are both possible.

Without of $\rho-\omega$ interference



With influence of $\rho-\omega$ interference in $M(\pi^+\pi^-)$ spectrum



S-wave – dashed, P-wave - solid

$X(3872) \to J/\psi(\psi')\gamma$

arXiv:1105.0177

Molecular model ⇒ $X \to \psi'\gamma$ is highly suppressed compared to $X \to J/\psi\gamma$.
BaBar[1] results ⇒ $\mathcal{B}(X \to \psi'\gamma)$ is 3 times larger than $\mathcal{B}(X \to J/\psi\gamma)$.
Can be an indication of a (c anti-c) admixture (in addition to a (D^0anti-D^{*0}) component).

Used statistics - 711 fb^{-1}.

$$\mathcal{B}(B^+ \to K^+ X) \times \mathcal{B}(X \to J/\psi\gamma) = (1.78^{+0.48}_{-0.44} \pm 0.12) \times 10^{-6}$$
$$\mathcal{B}(B^+ \to K^+ X) \times \mathcal{B}(X \to \psi'\gamma) < 3.45 \times 10^{-6} \text{ (90\% CL)}$$

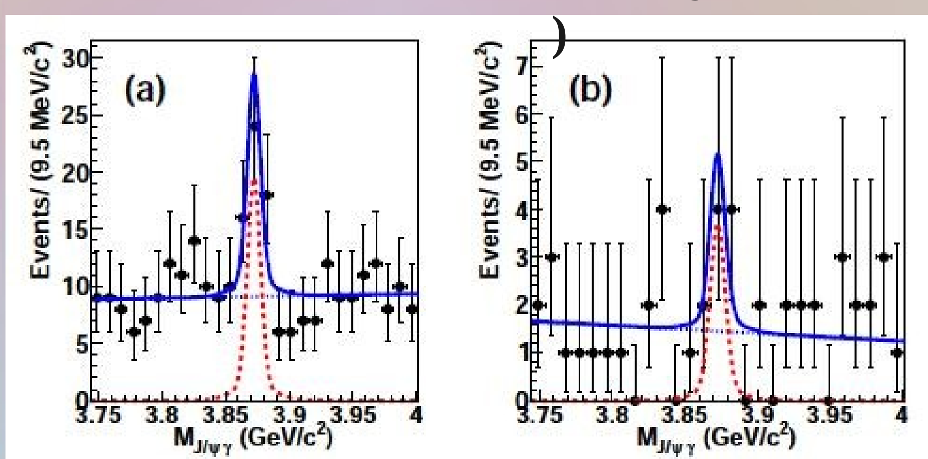
[1] PRL 102 132001

$\mathcal{B}(X \to \psi'\gamma) / \mathcal{B}(X \to J/\psi\gamma) < 2.1$ (90% CL)

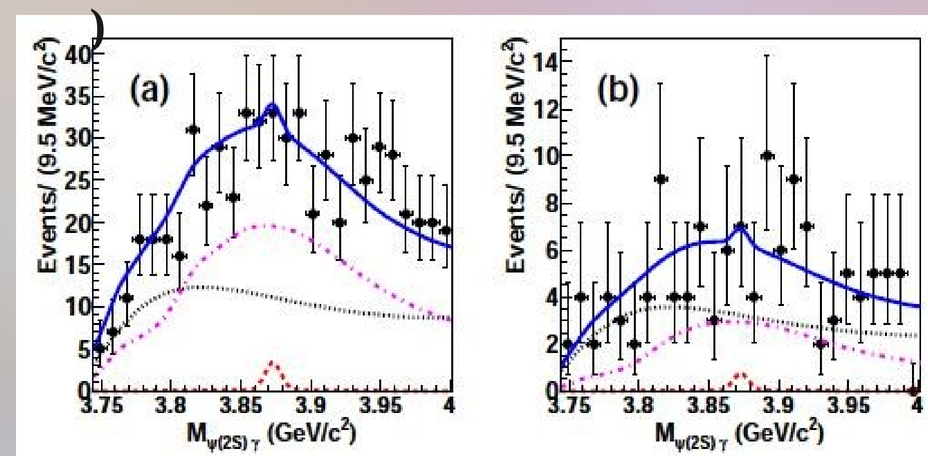
$\mathcal{B}(X \to \psi'\gamma) / \mathcal{B}(X \to J/\psi\gamma) = 3.4 \pm 1.4$

X may not have a large (c anti-c) admixture with a (D^0anti-D^{*0}) molecule.

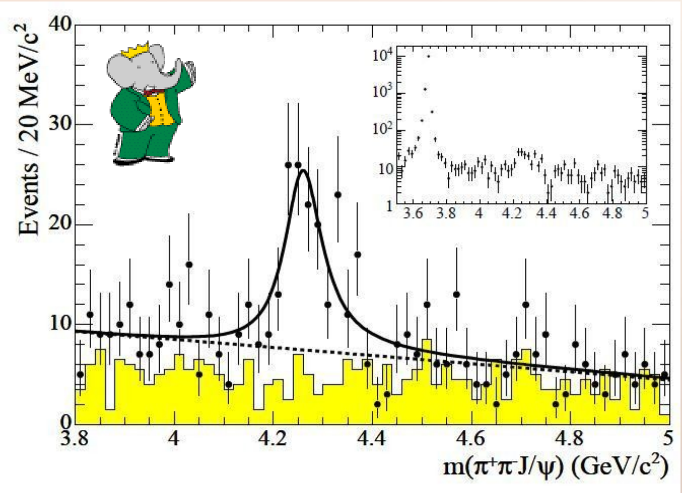
$B^+ \to K^+ X(\to J/\psi\gamma)$ $B^0 \to K_S^0 X(\to J/\psi\gamma)$



$B^+ \to K^+ X(\to \psi'\gamma)$ $B^0 \to K_S^0 X(\to \psi'\gamma)$



Y(4260)



First observed by BaBar[1] in 2005 in $e^+e^- \rightarrow (J/\psi\pi^+\pi^-)\gamma_{ISR}$.
Confirmed by Belle and CLEO.

Production in ISR $\Rightarrow$ Y(4260) is a 1^{--} state.

$\psi(2S)\pi^+\pi^-$

Family of 4 Y resonances (4008, 4260, 4360, 4660) does not fit into the charmonium spectrum.

Possible interpretations:

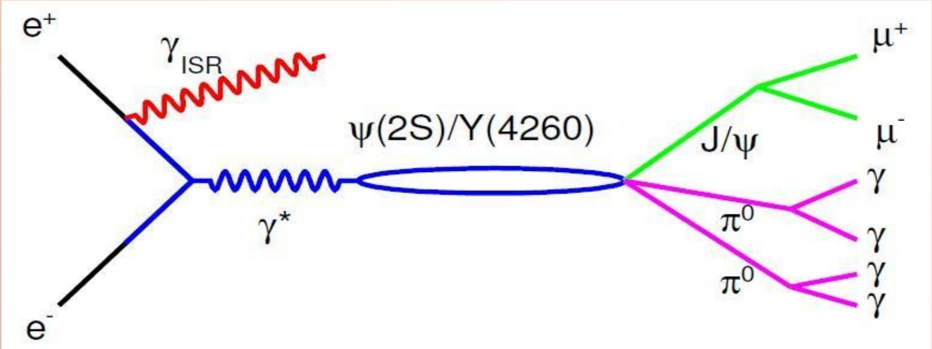
- Undiscovered ψ resonances ($3^3D_1(4560)$, $5^3S_1(4760)$, $4^3D_1(4810)$) ⟷ **Contra:** shifted by ~300 MeV, exotic decay channels
- Hybrids - most popular model ⟷ Y(4360) and Y(4660) (higher than DD^{**} threshold) are not seen in $e^+e^- \rightarrow$ hadrons
- Hadrocharmonium
- Tetraquarks
- (D anti-D_1) or (D^0 anti-D^*) molecules
- $f_0(980)\psi(2S)$ molecule for Y(4660)

[1] PRL 95 142001
[2] PRL 99 182004

$Y(4260)\to J/\psi\pi^0\pi^0$ (1)

Isospin symmetry ⇒ Y decays to ($J/\psi\pi^0\pi^0$) with half the rate of ($J/\psi\pi^+\pi^-$).
Large isospin symmetry violation could be a strong evidence of the exotic nature of Y.

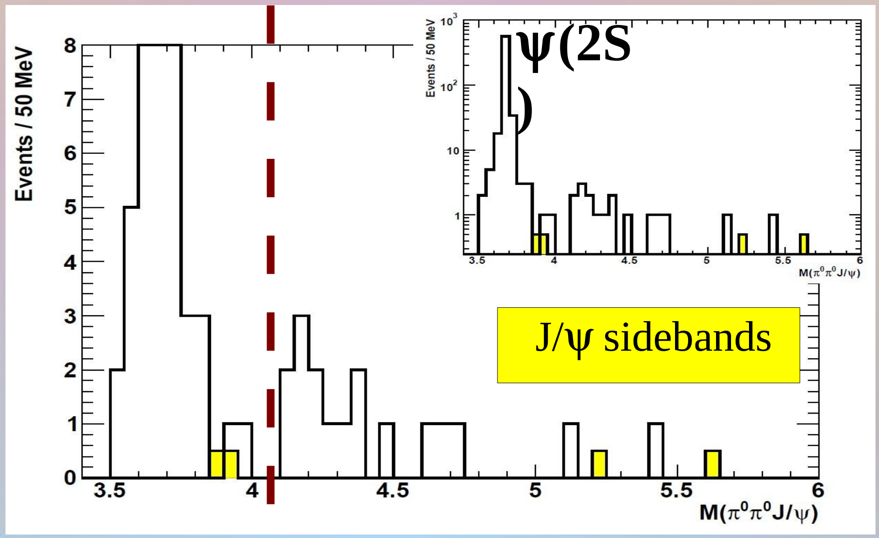
Study of cross-section $e^+e^-\to(J/\psi\pi^0\pi^0)\gamma_{ISR}$ as a function of mass is based on 790 fb^{-1}.



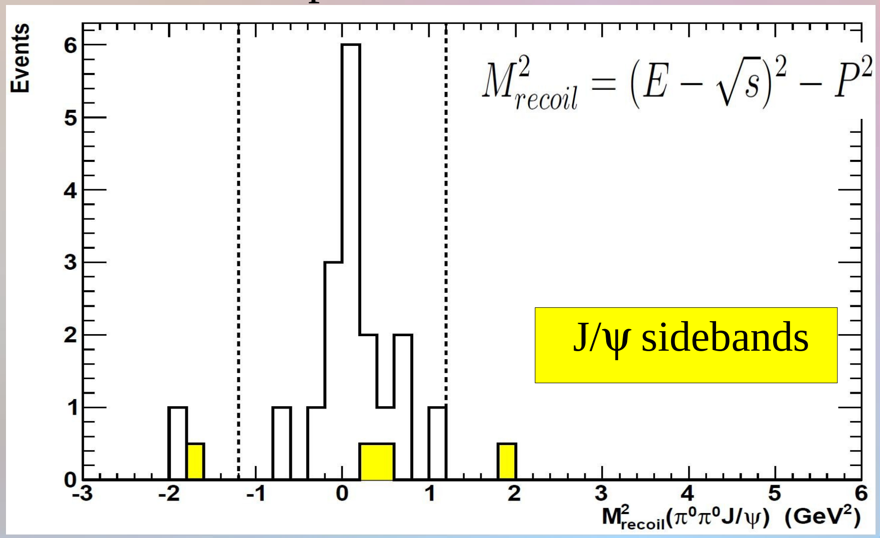
Analysis features:

- Require γ_{ISR} (lower backgrounds)
- $J/\psi\to\mu^+\mu^-$ ($J/\psi\to e^+e^-$ is wiped out by the skim conditions)

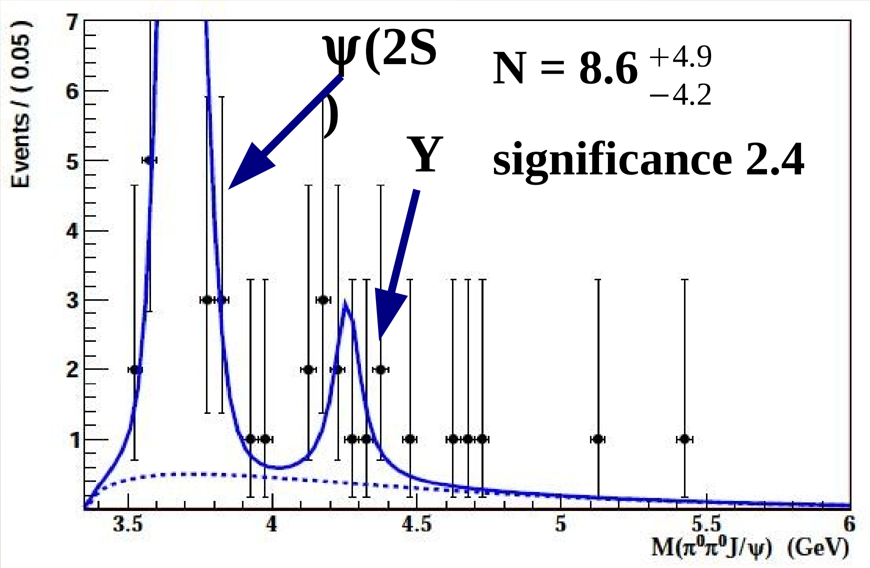
16 $J/\psi\pi^0\pi^0$ events above 4 GeV.



M^2_{recoil} distribution for events above 4 GeV is consistent with production via ISR.



$Y(4260) \to J/\psi\pi^0\pi^0$ (2)



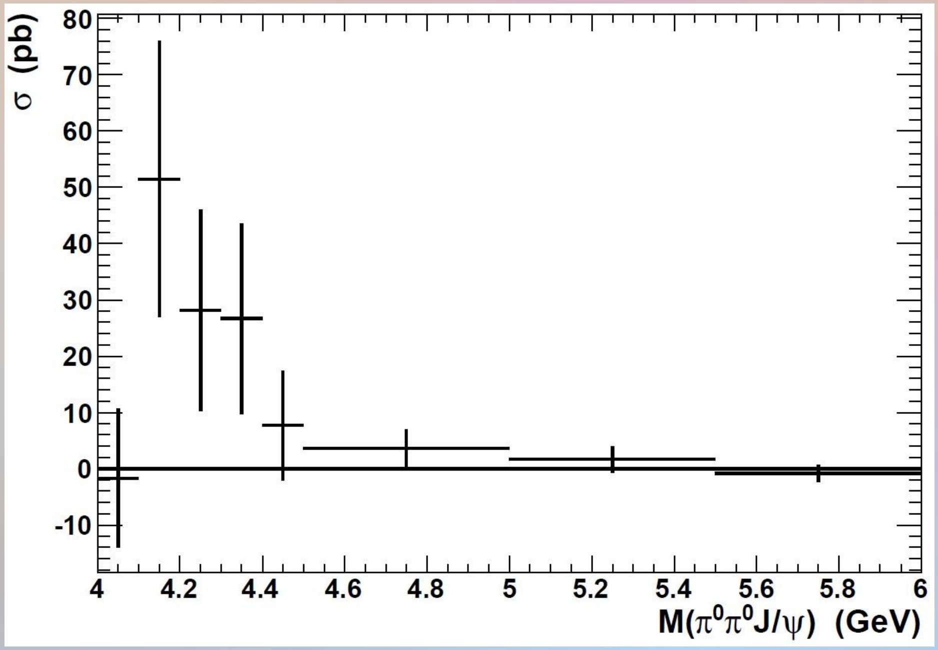
$\Gamma_{ee}(\psi(2S)) = (2.30 \pm 0.10)$ keV consistent with
$\Gamma_{ee}(\psi(2S)) = (2.35 \pm 0.04)$ keV [PDG]

Y parameters are fixed from PDG.
Background: $(x-x_{min})\cdot e^{c(x-x_{min})}$, $x_{min} = m_{J/\psi} - 2m_{\pi^0}$.
The shape accounts for effective luminosity and efficiency as a function of mass.

$\Gamma_{ee}\mathcal{B}(J/\psi\pi^0\pi^0) = (3.19^{+1.82}_{-1.53}{}^{+0.64}_{-0.35})$ eV

$\Gamma_{ee}\mathcal{B}(J/\psi\pi^+\pi^-) = 2\cdot(3.0^{+0.6}_{-0.5})$ eV [PDG]

$\Rightarrow$ consistency with the isospin expectation



$B^{\pm}\to K^{\pm}(K_S K\pi)^0$ (1)

arXiv:1105.0978

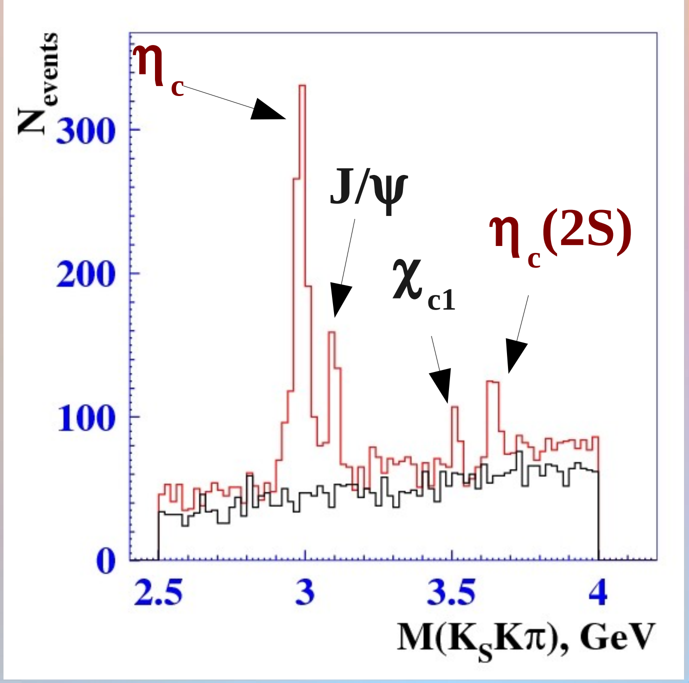
A large spread of measured η_c and, especially, $\eta_c(2S)$ parameters.

	BaBar[1][2]	**CLEO**[3]	**Belle**[4]
$M(\eta_c)$, MeV	2982.2±0.4±1.6	2981.8±1.3±1.5	2981.4±0.5±0.4
$\Gamma(\eta_c)$, MeV	31.7±1.2±0.8	24.8±3.4±3.5	36.6±1.5±2.0
$M(\eta_c(2S))$, MeV	3630.8±3.4±1.0	3642.9±3.1±1.5	3633.7±2.3±1.9
$\Gamma(\eta_c(2S))$, MeV	17.0±8.3±2.5	6.3±12.4±4.0	19.1±6.9±6.0

[1] PRD 81 052010 [2] PRL 92 142002
[3] PRL 92 142001 [4] NPPS 184 220

$B^{\pm}\to K^{\pm}(K_S K\pi)^0$ with the (c anti-c) formation from $(K_S K\pi)^0$ - signal

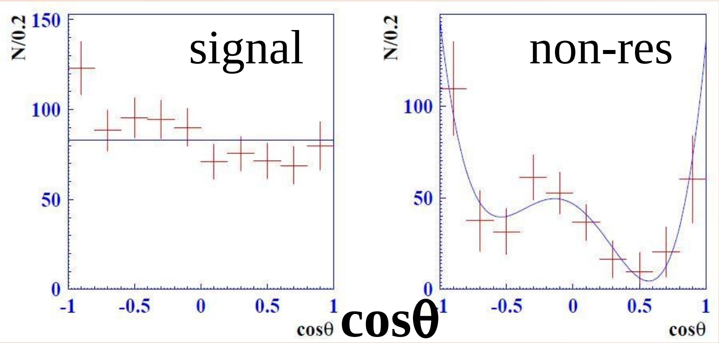
$B^{\pm}\to K^{\pm}(K_S K\pi)^0$ without the (c anti-c) formation – non-resonant component

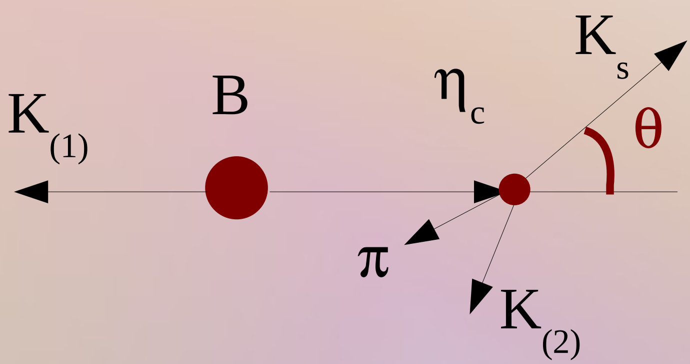


Same final state $\Rightarrow$ interference is inevitable!
Gives large model uncertainty (>50% for signal yield)
$\Rightarrow$ should be taken into account.

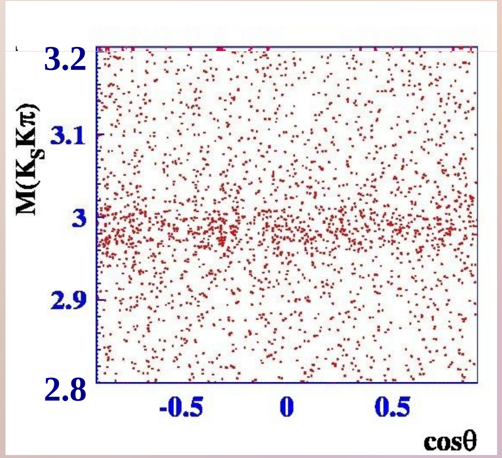
$B^{\pm}\to K^{\pm}(K_S K\pi)^0$ (2)

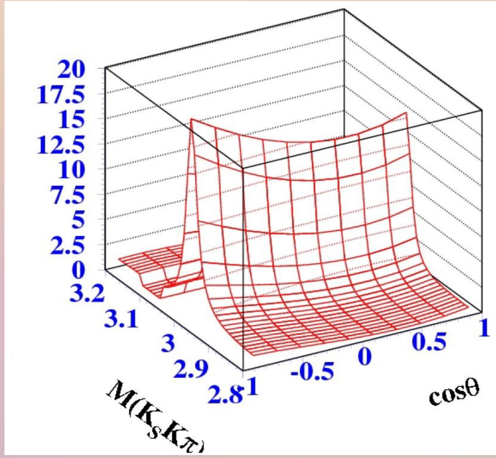
$M(K_S K\pi)$ and $\cos\theta$ distributions are used to distinguish signal and non-resonant components.



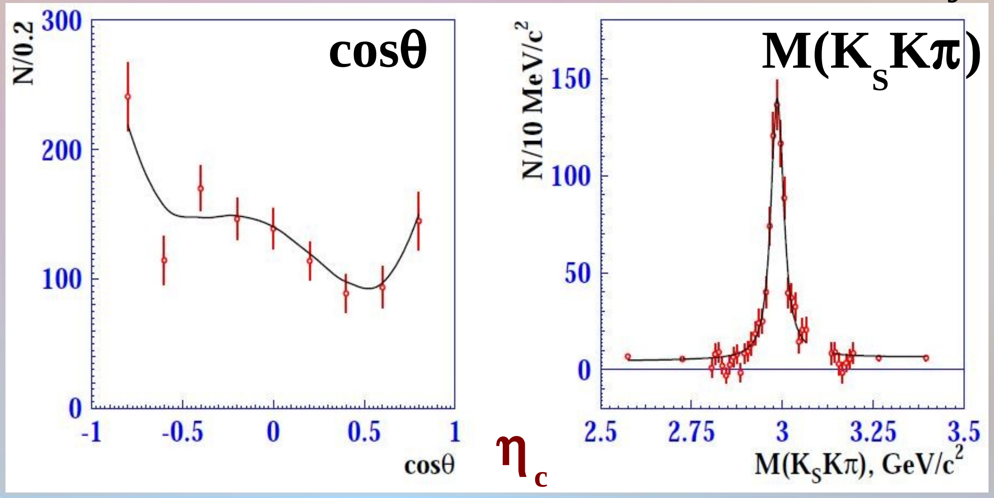


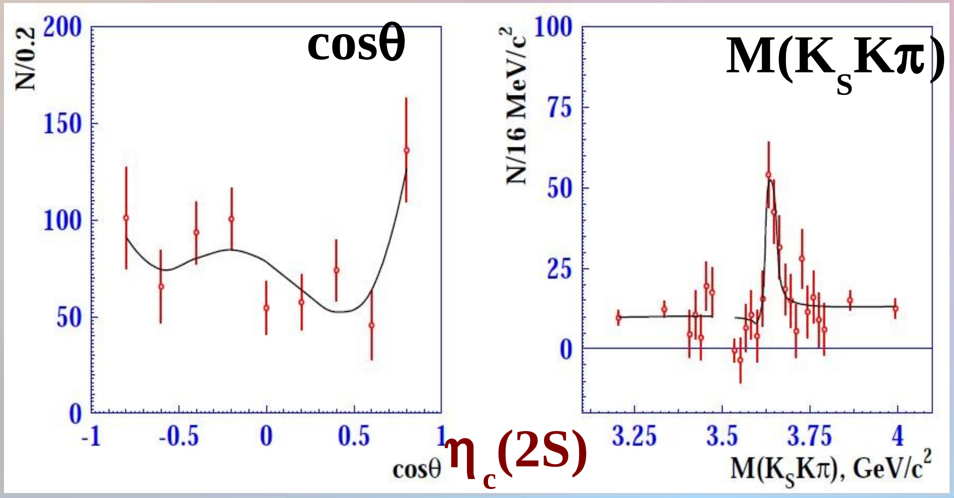
2D fit:





Projections:





$B^\pm \to K^\pm (K_S K\pi)^0$ (3)

$B^\pm \to K^\pm \eta_c,\ \eta_c \to (K_S K\pi)^0$	
$\mathcal{B} \times \mathcal{B}$, 10^{-6}	$26.7 \pm 1.4(stat)^{+2.9}_{-2.6}(syst) \pm 4.9(model)$
$M(\eta_c)$, MeV	$2985.4 \pm 1.5(stat)^{+0.2}_{-2.0}(syst)$
$\Gamma(\eta_c)$, MeV	$35.1 \pm 3.1(stat)^{+1.0}_{-1.6}(syst)$
$B^\pm \to K^\pm \eta_c(2S),\ \eta_c(2S) \to (K_S K\pi)^0$	
$\mathcal{B} \times \mathcal{B}$, 10^{-6}	$3.4^{+2.2}_{-1.5}(stat+model)^{+0.5}_{-0.4}(syst)$
$M(\eta_c(2S))$, MeV	$3636.1^{+3.9}_{-4.2}(stat+model)^{+0.5}_{-2.0}(syst)$
$\Gamma(\eta_c(2S))$, MeV	$6.6^{+8.4}_{-5.1}(stat+model)^{+2.6}_{-0.9}(syst)$

Some of the parameters of the 2D fitting function are dependent ⇒ model error.

The procedure of taking the interference into account:

- no assumptions about the phase or absolute value of the interference
- significant decrease of model error for $\mathcal{B}$
- comparable errors (despite the additional model error)

Results are consistent with those obtained in the most accurate measurements.

Conclusion

- New measurements of X(3872) parameters. UL on the width is significantly reduced.
- A difference in X(3872) masses produced via decays $B^+ \to K^+(J/\psi\pi^+\pi^-)$ and $B^0 \to K^0(J/\psi\pi^+\pi^-)$ is consistent with zero, which does not corroborate diquark-antidiquark model.
- Study of angular correlations and $M(\pi^+\pi^-)$ spectrum in $B^+ \to K^+(J/\psi\pi^+\pi^-) \Rightarrow$ both 1^{++} or 2^{-+} hypotheses for X(3872) are possible (more statistics is needed).
- No evidence of $X(3872) \to \psi'\gamma \Rightarrow$ hypothesis of large (c anti-c) admixture in the X(3872) is not confirmed.
- The value of $\mathcal{B}(Y(4260) \to J/\psi\pi^0\pi^0)$ is consistent with the expectation from isospin.
- Parameters of η_c and $\eta_c(2S)$ have been measured taking into account the interference between signal and non-resonant component.
- B-factories discovered a large number of new charmonium-like states and launched a new era of spectroscopy. Despite the large amount of data that was accumulated, statistics are still insufficient to resolve all the puzzles of exotic states. New Super B-factories are needed!

Backup slides

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

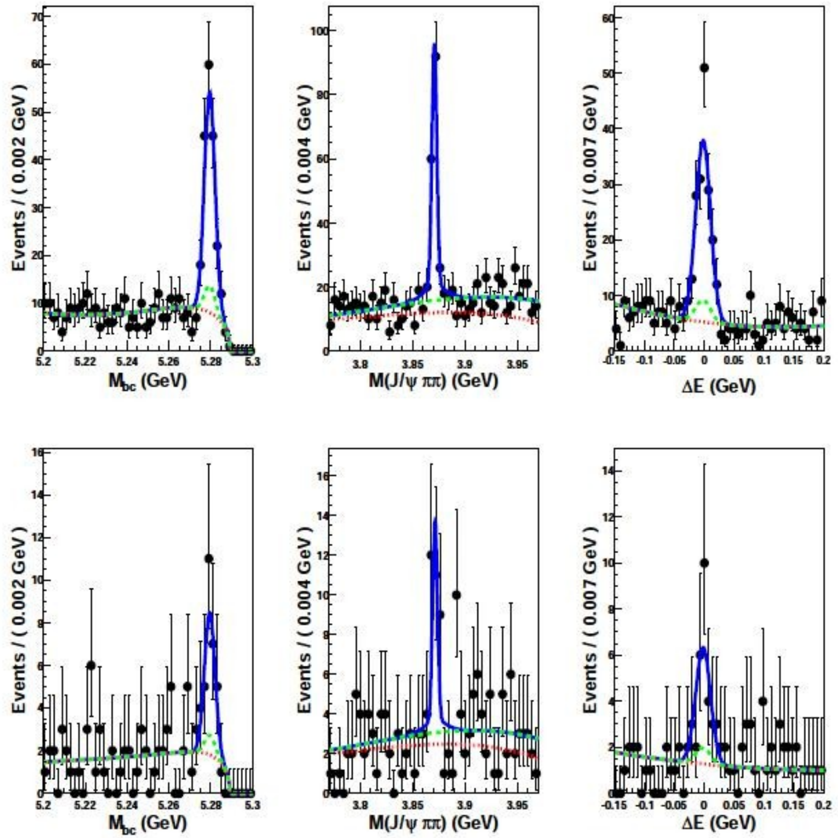


FIG. 2: The M_{bc} (left), $M(\pi^+\pi^- J/\psi)$ (center) and ΔE (right) distributions for $B^+ \to K^+ X(3872)$ (top) and $B^0 \to K_S X(3872)$ (bottom) event candidates within the signal regions of the other two quantities. The curves show the results of the fit described in the text .

TABLE IV: Systematic errors on the mass measurement.

Source	Systematic error (MeV)
$m_{J/\psi}$	0.01
$m_{\psi'}$	0.04
Bias correction	0.16
3-dim. fit model	0.03
MC model dependence	0.09
Quadrature sum	0.19

TABLE V: Systematic errors on the product branching fraction measurement.

Source	$K^+X(3872)$ (percent)	$K_SX(3872)$ (percent)	K_S/K^+ Ratio (percent)
N_{BB}	1.4	1.4	-
Secondary BF	1.0	1.0	-
MC statistics	1.0	1.0	1.4
MC model	2.1	2.1	-
Hadron ID	3.7	2.6	1.1
Lepton ID	1.1	1.1	-
Tracking	1.8	1.4	0.4
3-dim. fit model	3.0	5.0	6.0
K_S efficiency	-	4.5	4.5
Quadrature sum	6.0	8.1	7.7

$$\frac{d\Gamma}{d\Omega} = \sum_j \left| \sum_{\lambda_{J/\psi}\lambda_\rho} A^{J^{PC}}_{\lambda_{J/\psi}\lambda_\rho} D^1_{\lambda_{J/\psi}\ j}(\phi_{J/\psi}, \theta_{J/\psi}) D^1_{-\lambda_\rho 0}(\phi_\rho, \theta_\rho) D^{J_X}_{0\ (\lambda_{J/\psi}-\lambda_\rho)}(\phi_X, \theta_X) \right|^2$$

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

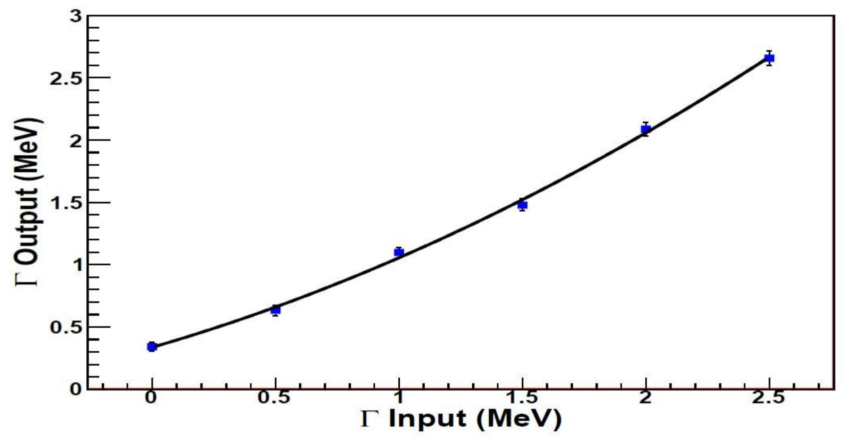


FIG. 3: Fitted vaules for $\Gamma_{X(3872)}$ (vertical) *versus* the MC generator input values (horizontal). The curve is the result of a fit to a second-order polynomial.

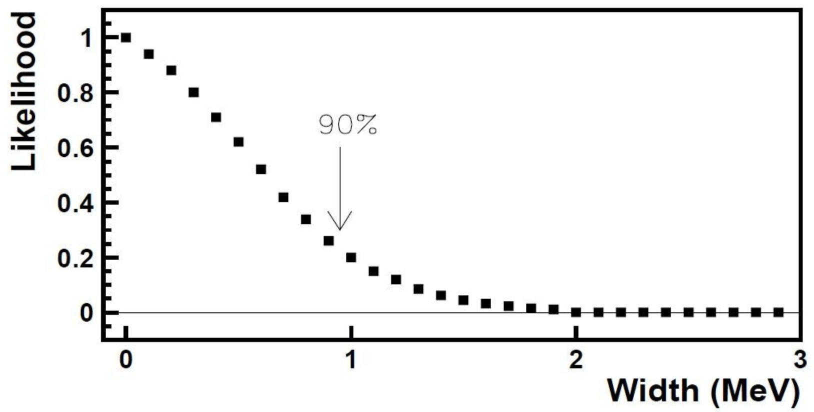


FIG. 4: Likelihood values from the $\Gamma_{X(3872)}$ scan described in the text. The region of the plot below the arrow contains 90% of the total area under the points.

	N_{sig}	r_ω	$N_{\rho\to\pi\pi}$	$N_{\omega\to\pi\pi}$	$N_{\rho-\omega\ \mathrm{interf}}$
S-wave	159 ± 15	0.07 ± 0.05	140.9	0.6 ± 0.5	17.8
P-wave	158 ± 15	$0.48^{+0.20}_{-0.14}$	93.2	$3.6^{+1.5}_{-1.1}$	60.0

$X(3872) \to J/\psi(\psi')\gamma$

Evidence of $B \to K\chi_{c2}$: $\mathcal{B}(B^+ \to K^+\chi_{c2})$ / $\mathcal{B}(B^+ \to K^+\chi_{c1}) = (2.25\,^{+0.73}_{-0.69} \pm 0.17) \times 10^{-2}$

more suppressed than expected in theory[2]

[2] NPB 811 155

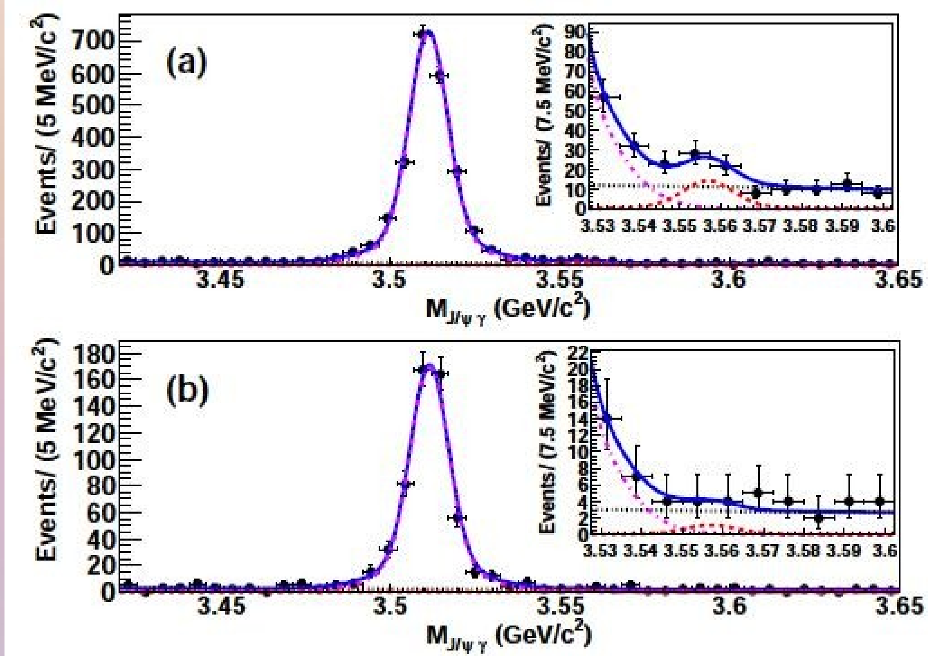
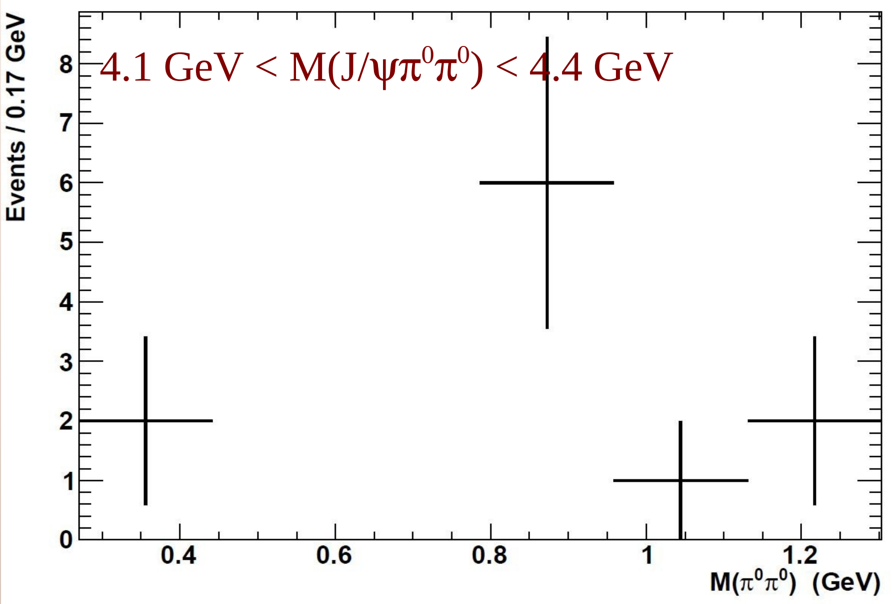


FIG. 1: $M_{J/\psi\gamma}$ distributions for (a) $B^+ \to \chi_{c1,c2}(\to J/\psi\gamma)K^+$ and (b) $B^0 \to \chi_{c1,c2}(\to J/\psi\gamma)K^0_S$ decays. The curves show the signal (pink dot-dashed for χ_{c1} and red dashed for χ_{c2}), and the background component (black dotted) as well as the overall fit (blue solid). The insets show a reduced range of $M_{J/\psi\gamma}$ and the contribution of the $B \to \chi_{c2}K$ peak.

$Y(4260) \rightarrow J/\psi\pi^0\pi^0$



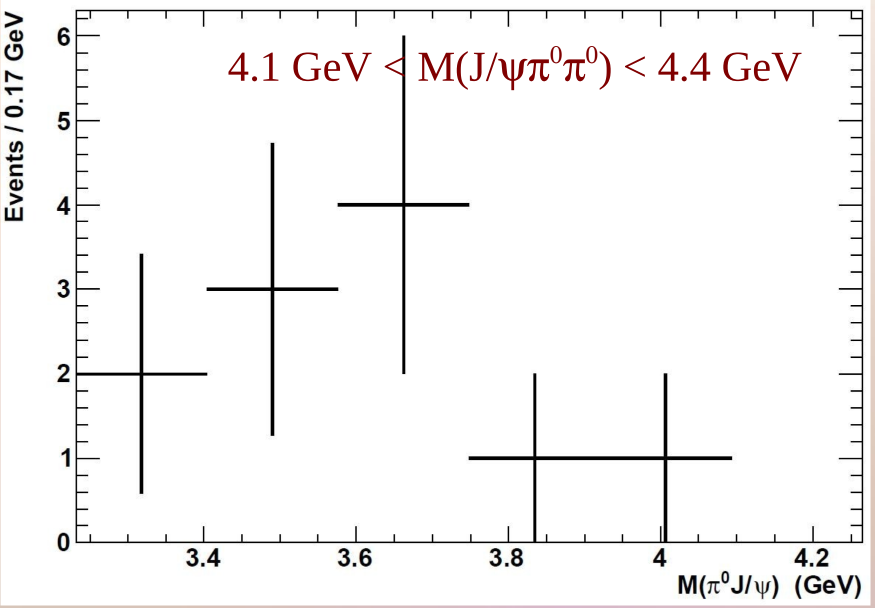


Table 1: Summary of systematic uncertainties.

Source	Error on yield (%)	
Luminosity	± 1.4	
Branching Fractions	± 1.0	
MuID	± 2.7	
Tracking	± 2.0	
Trigger	± 2.8	
Cut selection	$+3.2$	-2.8
$Y(4260)$ mass and width	$+5.5$	-5.7
Choice of fit function	$+18.3$	-7.8
Sum in quadrature	$+20$	-11

Table 2: Results of fit to $M(\pi^0\pi^0 J/\psi)$ spectrum. The non-resonant contribution is fit using a falling exponential with threshold function.

Parameter	Value	Positive error	Negative error	Units
$\Gamma_{e^+e^-} \cdot \mathcal{B}(Y(4260) \rightarrow \pi^0\pi^0 J/\psi)$	3.19	+1.82	-1.53	eV
$N(\psi(2S))$	629	+26	-25	
$\psi(2S)$ mean	3.6842	+0.0005	-0.0005	GeV
$N(1\gamma_{bkg})/N(\psi(2S))$	23	+4	-4	%
$N(>1\gamma_{bkg})/N(\psi(2S))$	3.6	+3.5	-3.4	%
N(non-resonant)	14	+8	-7	
Non-resonant shape parameter	-1.4	+0.7	-0.6	

$Y(4260) \to J/\psi \pi^0 \pi^0$

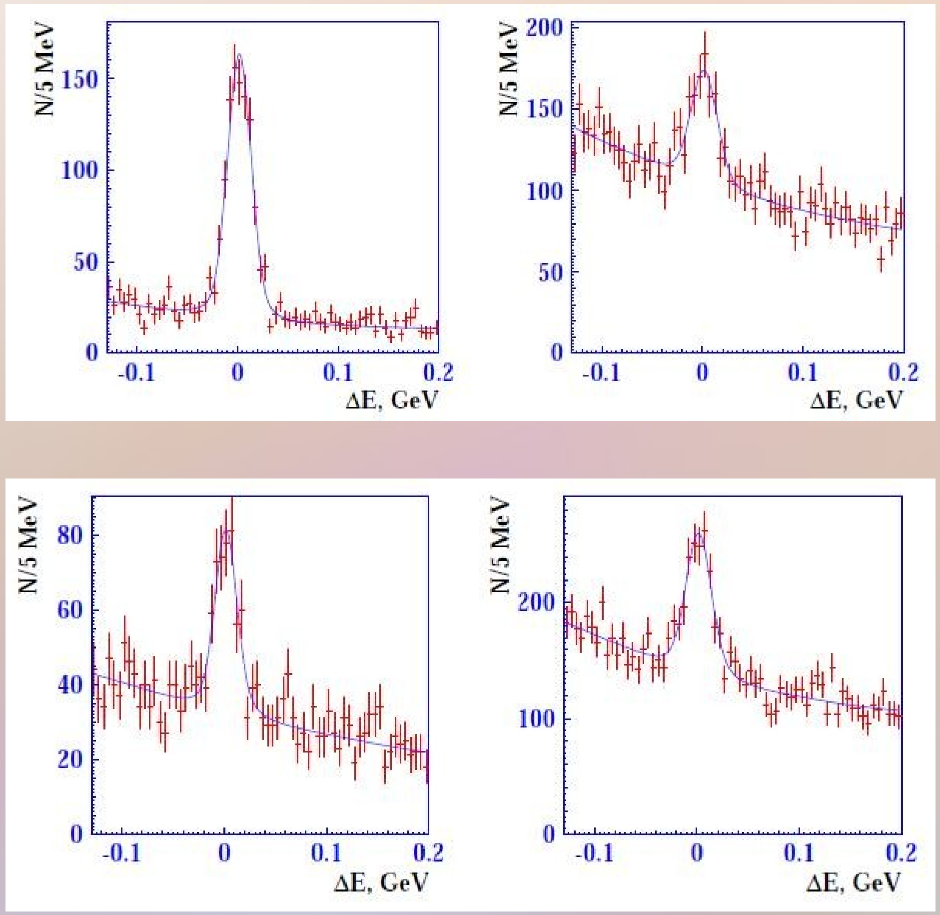
Cuts:

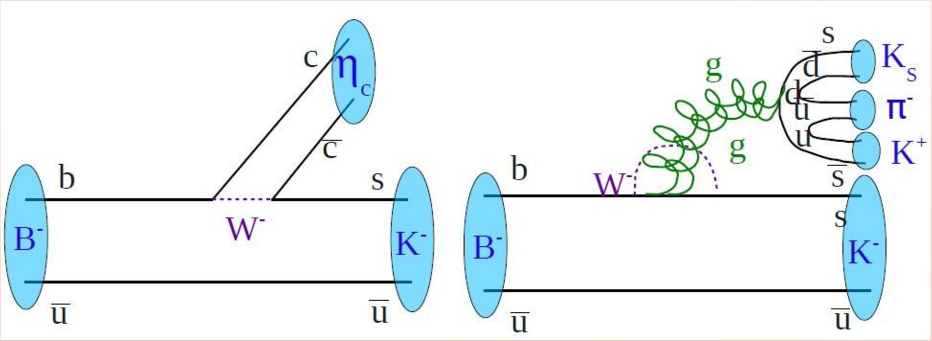
- Events with only two tracks passing track quality cuts
- MuID: One-hard, one-loose selection – require one track with MuID > 0.9, no MuID cut on other track.
  However if the second tracks has MuID equal to zero: require the track to be in the detector forward of $\cos(\theta) > -0.85$
- $|M(\mu\mu) - m_{J/\psi}| < 25$ MeV ($m_{J/\psi}$ is PDG mass)
- $E(\gamma) > 35$ MeV, quite low by Belle standards, with four π^0 photons in each event, the smallest energy photon distibution goes to quite low energies
- $|M(\gamma\gamma) - m_{\pi^0}| < 15$ MeV (m_{π^0} is PDG mass)
- $P_\perp(\pi^0\pi^0 J/\psi)\, w.r.t.\ \gamma_{ISR} < 0.05$ GeV, we require our candidate have the opposite the direction of the ISR photon.
- $|M^2_{recoil}| < 1.2$ GeV^2

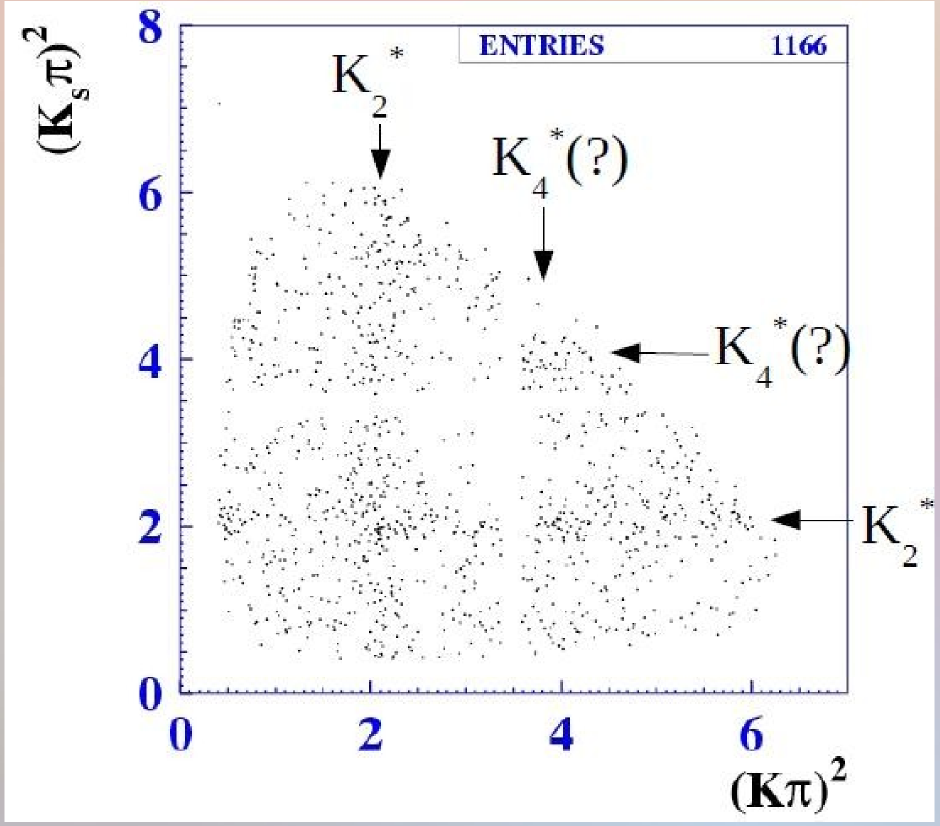
Multiple π^0 candidates, for a best candidate selection we minimise the sum of the absolute value of the two π^0 decay angles:

$$|\cos(\theta_\gamma)| = |\frac{E(\pi^0)}{P(\pi^0)} \cdot \frac{E(\gamma_1) - E(\gamma_2)}{E(\gamma_1) + E(\gamma_2)}|.$$

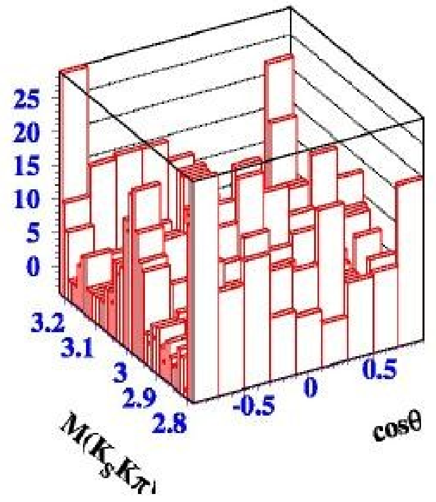
$B^{\pm} \to K^{\pm}(K_S K \pi)^0$

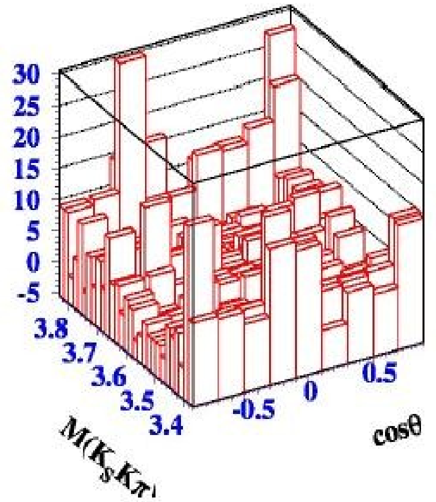






$B^\pm \to K^\pm (K_S K \pi)^0$





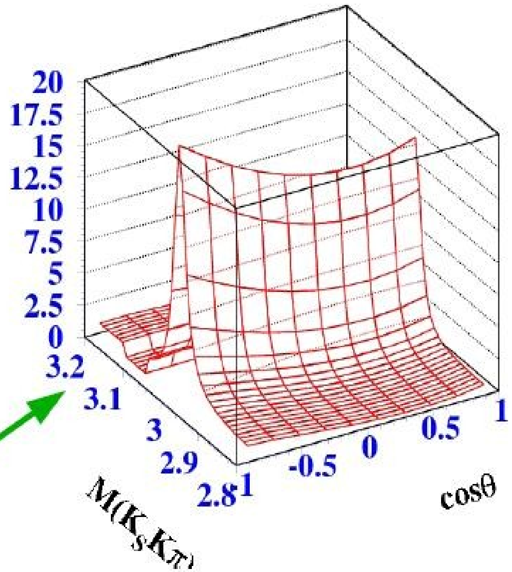
efficiency correction; S-wave non-res; P-wave non-res; D-wave non-res; η_c S-wave signal

$$F = \underbrace{(1+\varepsilon_1 x+\varepsilon_2 x^2)}_{\text{efficiency correction}} \cdot \int \Big| \Big(\frac{\sqrt{N}}{s-M^2+iM\Gamma} A_\eta(q_1,q_2) + \alpha A_S(q_1,q_2)\Big) S + \beta A_P(q_1,q_2) P + \gamma A_D(q_1,q_2) D \Big|^2 dq_1^{\,2} dq_2^{\,2} d\phi$$

- $x \equiv \cos\theta$
- $s \equiv M(K_s K\pi)$
- $S = \frac{1}{\sqrt{2}}$, $P = \sqrt{\frac{3}{2}}\, x$, $D = \frac{3}{2}\sqrt{\frac{5}{2}}\,(x^2-1/3)$
- $\int |A_{\eta,S,P,D}(q_1,q_2)|^2 \, dq_1^{\,2} dq_2^{\,2} d\phi = 1$

η_c region: J/ψ veto

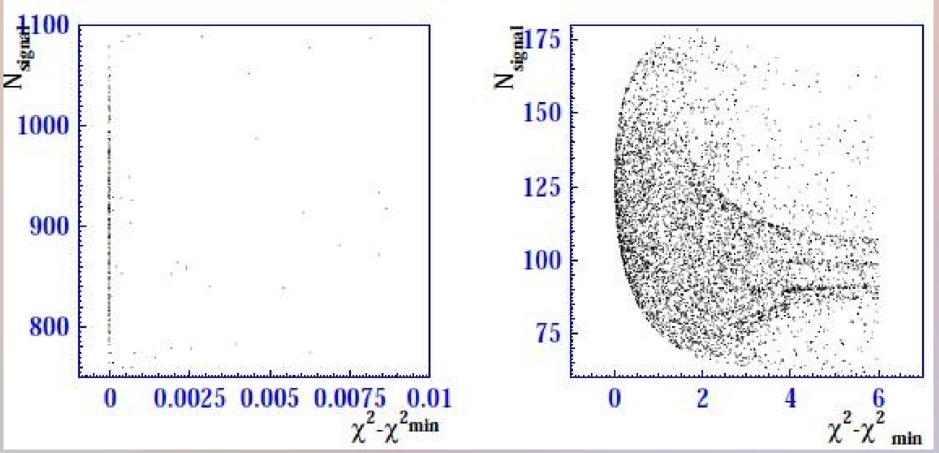
$\eta_c(2S)$ region: χ_{c1} veto

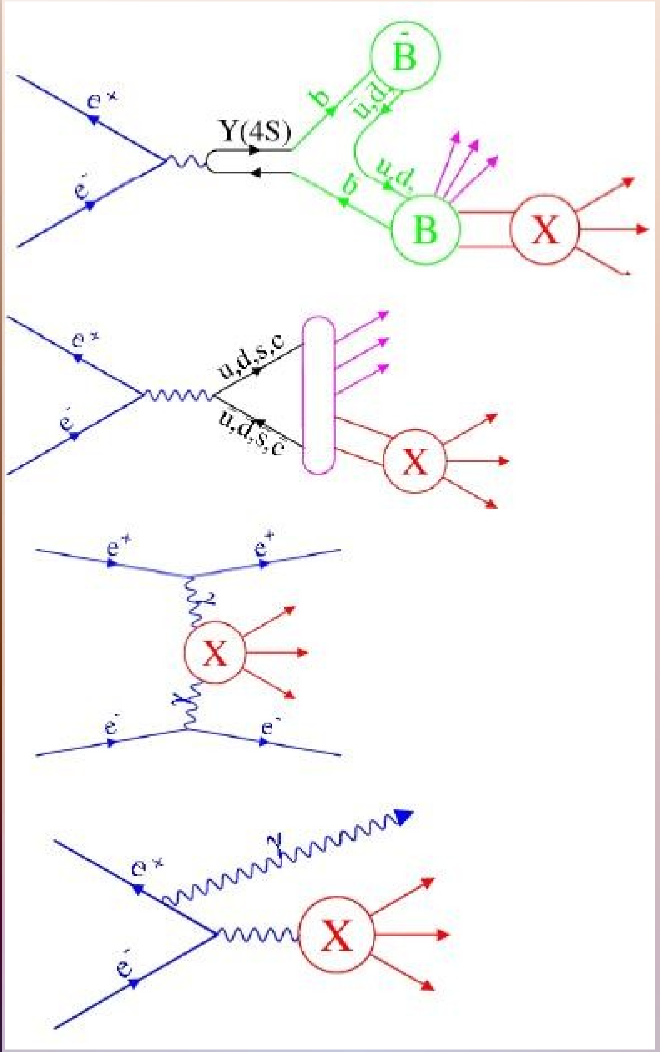


$B^{\pm} \to K^{\pm}(K_S K\pi)^0$

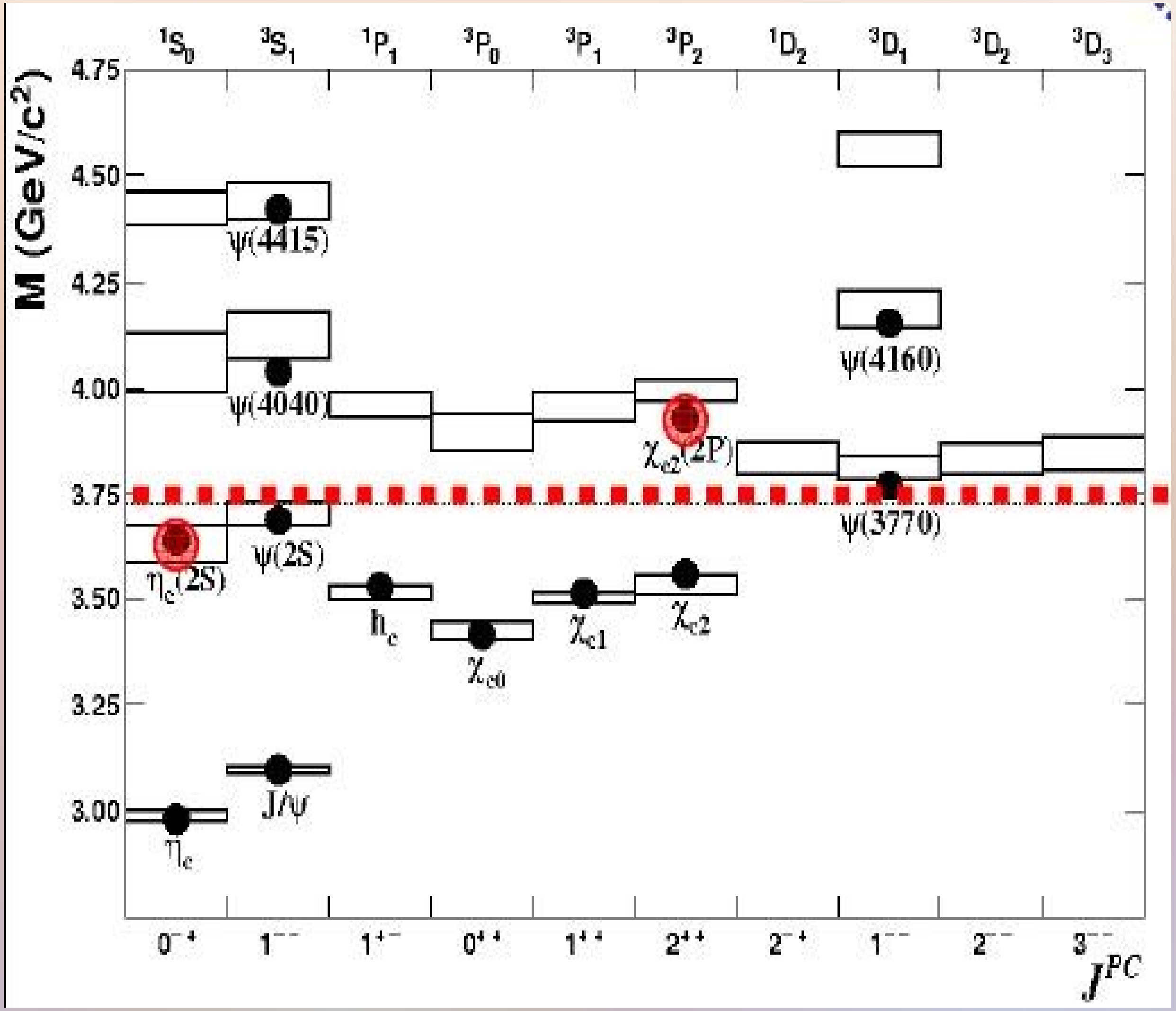
Source	$B^{\pm} \to K^{\pm}(K_S K \pi)^0$	
	η_c	$\eta_c(2S)$
Number of $B\bar{B}$ pairs	1.3	1.3
$\mathcal{B}(K_S \to \pi^+\pi^-)$	0.1	0.1
Model efficiency dependence	$^{+8.6}_{-6.7}$	$^{+2.0}_{-1.5}$
Background approximation	—	+2.3
Bin size	−3.3	$^{+13.3}_{-3.9}$
ΔE cut	−2.2	+2.3
Detector resolution	+1.1	$^{+4.7}_{-8.6}$
M_{inv} efficiency dependence	+2.2	+0.8
Track reconstruction	3	3
$K^{\pm}$ identification	1.6	1.6
$\pi^{\pm}$ identification	1.5	1.5
K_S reconstruction	4.4	4.4
Total, %	$^{+10.7}_{-9.8}$	$^{+15.8}_{-11.9}$

Source	η_c		$\eta_c(2S)$	
	Mass	Width	Mass	Width
Background approximation	—	—	+0.2	−0.1
Bin size	+0.2	−1.0	−1.1	+2.4
Detector resolution	−0.1	$^{+1.0}_{-1.2}$	$^{+0.5}_{-0.1}$	$^{+1.8}_{-0.9}$
Scale uncertainty	−2.0	—	−1.7	—
Total, MeV/c^2	$^{+0.2}_{-2.0}$	$^{+1.0}_{-1.6}$	$^{+0.5}_{-2.0}$	$^{+2.6}_{-0.9}$



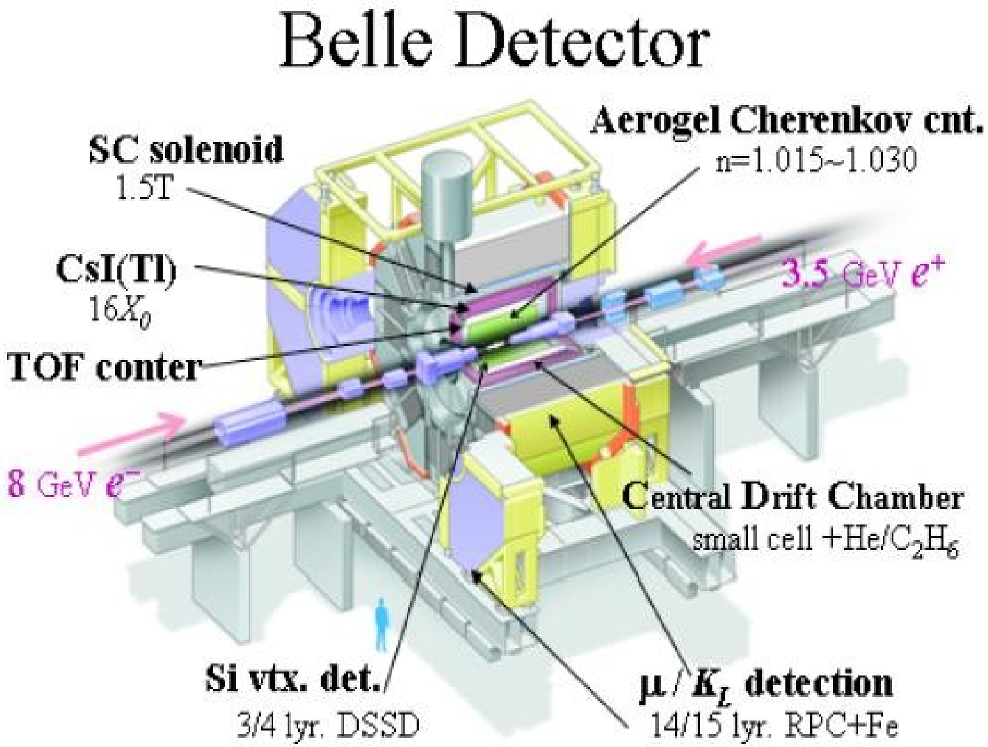


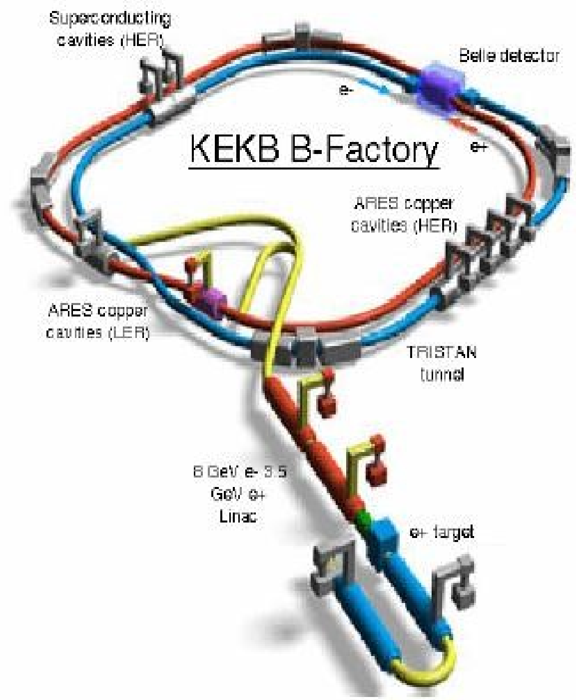
B̄
b
u,d
Y(4S)
u,d
b
B
X
e+
e-
u,d,s,c
u,d,s,c
X
γ
X
e+
e-
γ
X



$^1S_0$ $^3S_1$ $^1P_1$ $^3P_0$ $^3P_1$ $^3P_2$ $^1D_2$ $^3D_1$ $^3D_2$ $^3D_3$
M (GeV/c²)
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
ψ(4415)
ψ(4040)
ψ(4160)
χ_{c2}(2P)
ψ(3770)
η_c(2S)
ψ(2S)
h_c
χ_{c0}
χ_{c1}
χ_{c2}
J/ψ
η_c
0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++} 2^{-+} 1^{--} 2^{--} 3^{--}
J^{PC}

State	M (MeV)	Γ(MeV)	J^{PC}	Process (mode)	Experiment
B-decays					
$\eta_c(2S)$	3637 ± 4	14 ± 7	0^{-+}	$K(K^0_S K^- \pi^+)$	Belle(2002), BaBar, CLEO
$X(3872)$	3871.52 ± 0.20	1.3 ± 0.6	1^{++}	$K(\pi^+\pi^- J/\psi)$ $K(D^{*0}\bar{D}^0),...$	Belle(2003), BaBar,CDF,D0
$Y(3940)$	3915.7 ± 4.2	41 ± 12	$0/2^{?+}$	$K(\omega J/\psi)$	Belle(2004), BaBar
$Z_1(4050)^+$	4051^{+24}_{-43}	82^{+51}_{-55}	?	$K(\pi^+\chi_{c1}(1P))$	Belle (2008)
$Z_2(4250)^+$	4248^{+185}_{-45}	177^{+321}_{-72}	?	$K(\pi^+\chi_{c1}(1P))$	Belle (2008)
$Z(4430)^+$	4443^{+24}_{-18}	107^{+113}_{-71}	?	$K(\pi^+\psi(2S))$	Belle (2007)
Double charmonium					
$X(3940)$	3942^{+9}_{-8}	37^{+27}_{-17}	$?^{?+}$	$J/\psi(D\bar{D}^*)$	Belle (2007)
$X(4160)$	4156^{+29}_{-25}	139^{+113}_{-65}	$?^{?+}$	$J/\psi(D^*\bar{D}^*)$	Belle (2007)
ISR					
$Y(4008)$	4008^{+121}_{-49}	226 ± 97	1^{--}	$(\pi^+\pi^- J/\psi)$	Belle (2007)
$Y(4260)$	4263 ± 5	108 ± 14	1^{--}	$(\pi^+\pi^- J/\psi)$	BaBar (2005), Belle, CLEO
$Y(4360)$	4353 ± 11	96 ± 42	1^{--}	$(\pi^+\pi^- \psi(2S))$	BaBar (2007), Belle
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$(\Lambda_c\Lambda_c)$	Belle (2007)
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$(\pi^+\pi^- \psi(2S))$	Belle (2007)
Two photons					
$\chi_{c2}(2P)$	3927.2 ± 2.6	24.1 ± 6.1	2^{++}	$(D\bar{D})$	Belle(2005), BaBar
$X(3915)$	3914 ± 4	23^{+10}_{-13}	$0, 2^{++}$	$(\omega J/\psi)$	Belle(2009)
$X(4350)$	$4350.6^{+4.6}_{-5.1}$	$13.3^{+18.4}_{-10.0}$	$0,2^{++}$	$(\phi J/\psi)$	Belle(2009)
Energy scan and Υ transitions					
$\eta_b(1S)$	9390.7 ± 2.9	?	0^{-+}	$\gamma + (...)$	BaBar(2008), CLEO
Y_b	10889.6 ± 2.3	$54.7^{+8.9}_{-7.6}$	1^{--}	$\pi^+\pi^-\Upsilon(nS)$	Belle (2008)





- 3.5 GeV $e^+ \times$ 8.0 GeV e^-.
- $\mathcal{L}_{\max} = 2.1 \times 10^{34} cm^{-2} s^{-1}$
- Continuous injection $\rightarrow 1.1\,\mathrm{fb}^{-1}/\mathrm{day}$.
- $\int \mathcal{L} dt \approx 1\, ab^{-1}$