Search for B decays to final states with the η_c meson

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Belle collaboration

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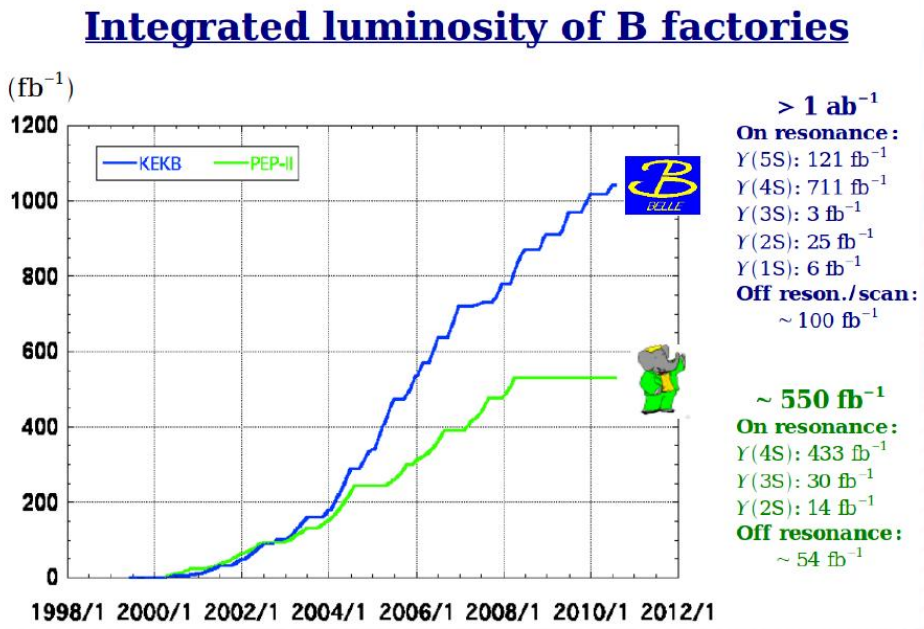
Motivation

Recently many new charmonium-like states were observed in the mass region above the $D\bar{D}$ threshold. Decays of B mesons provide a great opportunity to study these exotic states and search for new ones.

- $D^{(*)}\bar{D}^{(*)}$ bound states ("X(3872)-like" particles)
- Neutral partners of $Z(3900)^{\pm}$ and $Z(4020)^{\pm}$
- X(3915)



Studied modes:

1) $B^{\pm} \to K^{\pm}(\eta_c \pi^+ \pi^-)$
2) $B^{\pm} \to K^{\pm}(\eta_c \omega)$
3) $B^{\pm} \to K^{\pm}(\eta_c \eta)$
4) $B^{\pm} \to K^{\pm}(\eta_c \pi^0)$

Selection criteria

Applied cuts (~2.5 σ_{MC}):

- $|\Delta E| < 0.02$ GeV
- $|M_{bc} - 5.279| < 0.006$ GeV
- $|\eta_c - 2.9854| < 0.06$ GeV
- $|K_S - 0.498| < 0.012$ GeV
- $|\omega - 0.783| < 0.025$ GeV
- $|\eta - 0.548| < 0.02$ GeV (for 2γ mode), 0.01 GeV (for 3π mode)
- $|\pi^0 - 0.135| < 0.01$ GeV
- $|\cos\theta_B| < 0.8$
- $|\cos\theta_{thrust}| < 0.8$

+

Best candidate:

- $|M(\pi^+\pi^-) - M(K_S)| \rightarrow$ min
- $|M(K_S K\pi) - M(\eta_c)| \rightarrow$ min
- $|M(\gamma\gamma) - M(\pi^0)| \rightarrow$ min
- $|M(\gamma\gamma) - M(\eta)| \rightarrow$ min
- Δz of charged particles $\rightarrow$ min

Standard cuts:

- $|\Delta R| < 0.2$ cm, $|\Delta Z| < 2.5$ cm
- $P_t > 0.1$ GeV/c^2
- PID(K/π) > 0.6 for K mesons
- PID(π/K) > 0.2 for π mesons
- $18° < \theta_{track} < 152°$

Search for $B^{\pm} \to K^{\pm} \eta_c$ + hadrons (1)

$B^{\pm} \to K^{\pm}\eta_c\pi^+\pi^-$

Most of the events are from the decay $B^{\pm} \to K^{\pm}(K_S K\pi)\pi^+\pi^-$ (non-resonant)

$B^{\pm} \to K^{\pm}\eta_c\pi^0$

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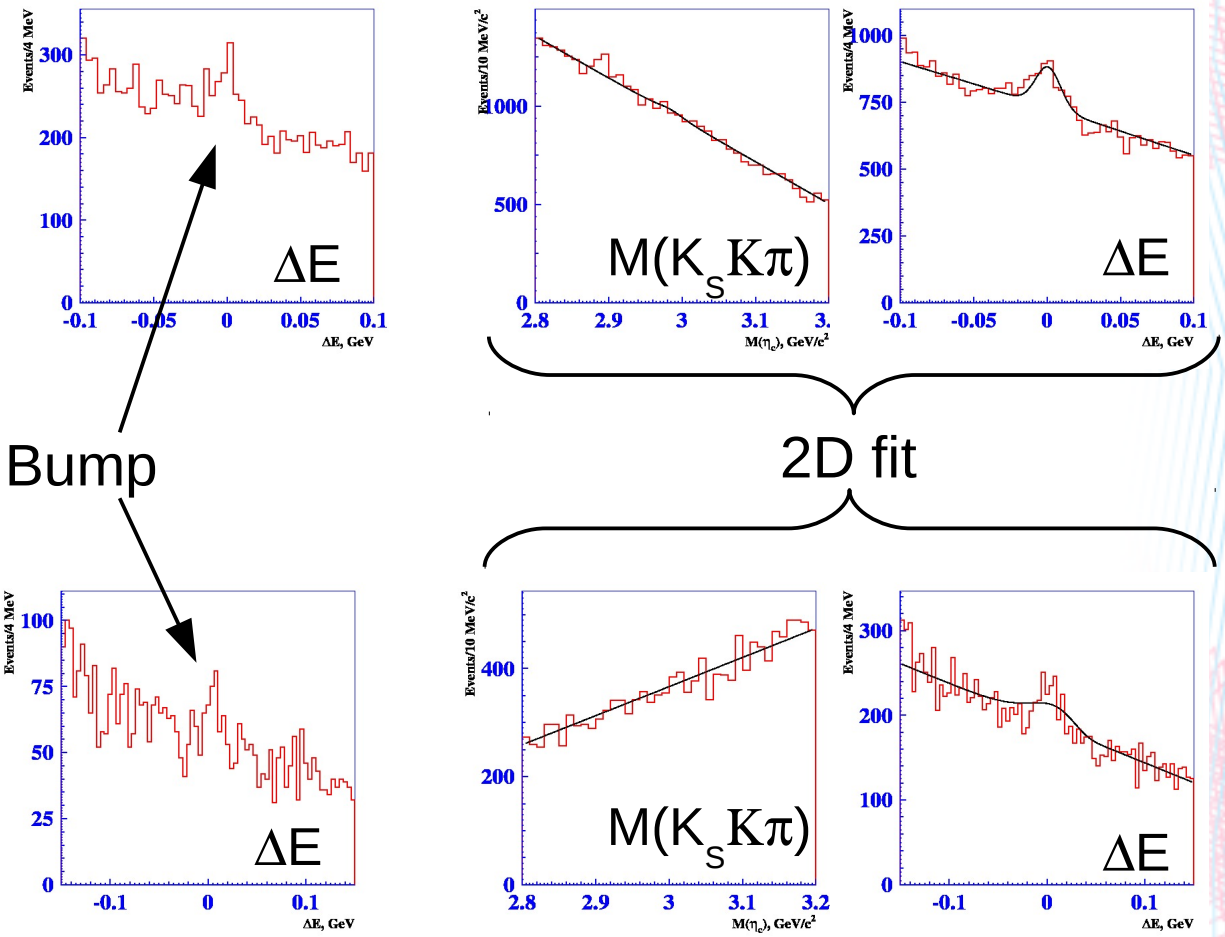
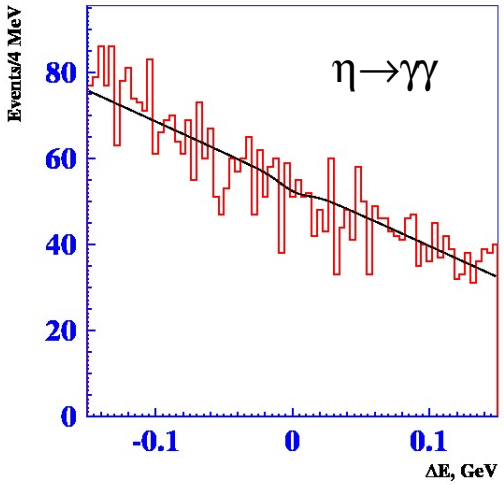
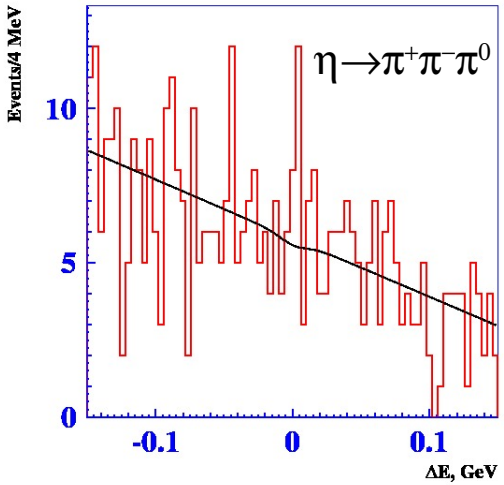


Search for $B^{\pm} \to K^{\pm} \eta_c$ + hadrons (2)

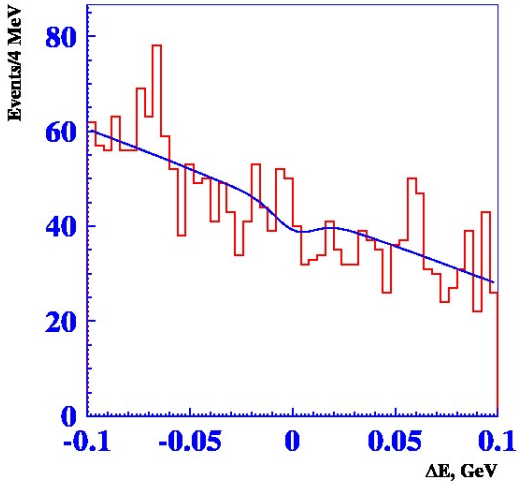
$B^{\pm} \to K^{\pm}\eta_c\eta$

Combined fit





$B^{\pm} \to K^{\pm}\eta_c\omega$

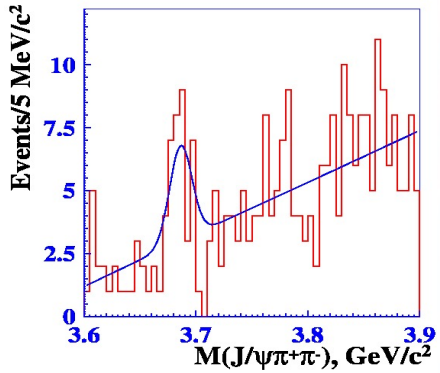


Decay mode	Efficiency, %	Yield
$B^{\pm} \to K^{\pm}\eta_c\omega$	0.53 ± 0.01	-41 ± 27
$B^{\pm} \to K^{\pm}\eta_c\pi^+\pi^-$	2.84 ± 0.02	155 ± 72
$B^{\pm} \to K^{\pm}\eta_c\pi^0$	3.69 ± 0.01	-1.9 ± 12.1
$B^{\pm} \to K^{\pm}\eta_c\eta$,		
$\eta \to \gamma\gamma$	3.05 ± 0.01	-14 ± 26
$\eta \to \pi^+\pi^-\pi^0$	0.69 ± 0.01	-1.8 ± 3.4

Search for «X(3872)-like» decays to η_c modes (1)

Motivation:

- X(3872) was first observed by Belle in $B \to K(J/\psi\pi^+\pi^-)$. Angular analysis of this mode performed by LHCb determined all quantum numbers: 1^{++}.
- If X(3872) is a $D^0\overline{D}^{*0}$ molecule, there may be other «X(3872)-like» particles with different quantum numbers, that are also bound states of $D^{(*)}$ mesons.
  - $X_1(3872)$: $(D^0\overline{D}^{*0} - \overline{D}^0D^{*0})$ combination: $J^{PC}=1^{+-}$, decays $X\to\eta_c\omega$, $X\to\eta_c\rho$
  - X(3730): $(D^0\overline{D}^0 + \overline{D}^0D^0)$ combination: $J^{PC}=0^{++}$, decays $X\to\eta_c\eta$, $X\to\eta_c\pi^0$
  - X(4014): $(D^{*0}\overline{D}^{*0} + \overline{D}^{*0}D^{*0})$ combination: $J^{PC}=0^{++}$, decays $X\to\eta_c\eta$, $X\to\eta_c\pi^0$



Analysis features:

- X is produced in charged B decays: $B^\pm \to K^\pm X$
- $\eta_c \to K_S K\pi$, $K_S \to \pi^+\pi^-$
- combined fit of 2 decay modes of η ($\gamma\gamma$ and $\pi^+\pi^-\pi^0$)
- test mode $B^\pm \to K^\pm\psi(2S)$, $\psi(2S) \to J/\psi\pi^+\pi^-$ gives results consistent with PDG

Search for «X(3872)-like» decays to η_c modes (2)

$B^{\pm} \to K^{\pm} X$

$X_1(3872)$

$\to \eta_c \pi^+ \pi^-$

$\to \eta_c \omega,\ \omega \to \pi^+ \pi^- \pi^0,\ \pi^0 \to \gamma\gamma$

X(3730)

X(4014)

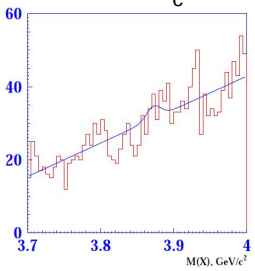
$\to \eta_c \eta$

$\to \gamma\gamma$

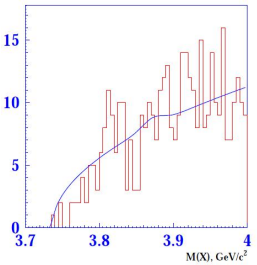
$\to \pi^+ \pi^- \pi^0,\ \pi^0 \to \gamma\gamma$

$\to \eta_c \pi^0,\ \pi^0 \to \gamma\gamma$

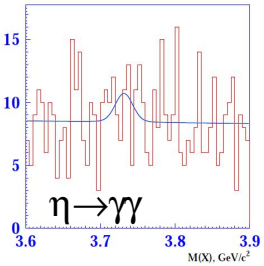
X(3872)→ $\eta_c \pi^+ \pi^-$

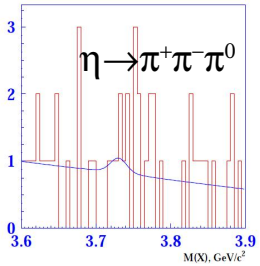


X(3872)→ $\eta_c \omega$

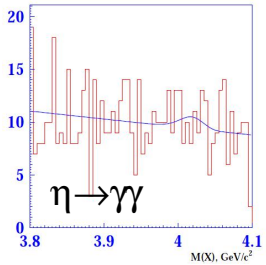


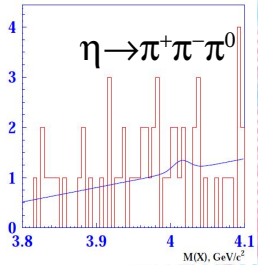
X(3730)→ $\eta_c \eta$



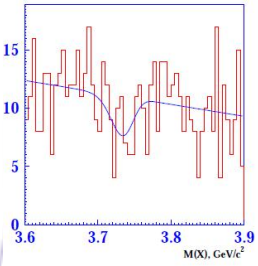


X(4014)→ $\eta_c \eta$

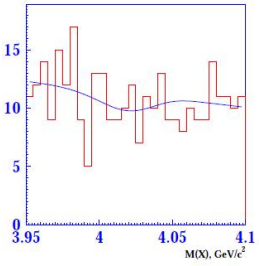




X(3730)→ $\eta_c \pi^0$



X(4014)→ $\eta_c \pi^0$



Search for «X(3872)-like» decays to η_c modes (3)

Decay mode	Efficiency, %	Yield
$X_1(3872) \to \eta_c\pi^+\pi^-$	7.95 ± 0.02	17.9 ± 16.5
$X_1(3872) \to \eta_c\omega$	1.92 ± 0.02	6.0 ± 12.5
$X(3730) \to \eta_c\eta$,		
$\eta \to \gamma\gamma$	6.57 ± 0.02	13.8 ± 9.9
$\eta \to \pi^+\pi^-\pi^0$	1.18 ± 0.01	1.4 ± 1.0
$X(3730) \to \eta_c\pi^0$	6.52 ± 0.02	-25.6 ± 10.4
$X(4014) \to \eta_c\eta$,		
$\eta \to \gamma\gamma$	7.09 ± 0.02	8.9 ± 11.0
$\eta \to \pi^+\pi^-\pi^0$	1.78 ± 0.01	1.3 ± 1.6
$X(4014) \to \eta_c\pi^0$	7.55 ± 0.02	-8.1 ± 13.2

$Z(3900)^0$ & $Z(4020)^0$ (1)

Motivation:

Recently a new charged state $Z(3900)^{\pm}$ was found in Y(4260) decays by the BESIII and Belle. Since this particle was observed in the decay to $\pi^{\pm}J/\psi$, it should contain at least four quarks. Later BESIII reported an observation of another decay channel of assumingly the same exotic state $Z(3885)^{\pm} \to (D\bar{D}^*)^{\pm}$. The analysis based on the CLEOc data confirmed the decay of this exotic state to the $\pi^{\pm}J/\psi$ and also reported evidence for its neutral isotopic partner $Z(3900)^0$.

$J^P = 1^+$

Preliminary results by BESIII for $Z(3900)^0$: $M=(3894.8\pm2.3)$ MeV, $\Gamma=(29.6\pm8.2)$ MeV **10σ!**

Another exotic charged state $Z(4020)^{\pm}$ was observed by BESIII in decays to $\pi^{\pm}h_c$ and $(D^*\bar{D}^*)^{\pm}$.

$J^P = 0^-, 1^{\pm}$

Preliminaty results by BESIII for $Z(4020)^0$: $M=(4023.6\pm2.2\pm3.9)$ MeV, Γ fixed from $Z(4020)^{\pm}$ **$>5\sigma$!**

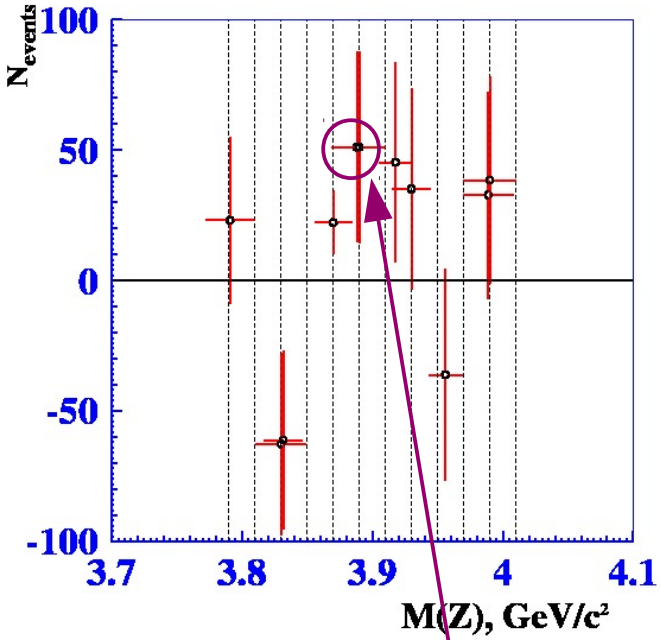
Analysis features:

- Z^0 is produced in charged B decays: $B^{\pm} \to K^{\pm}Z^0 \to K^{\pm}(\eta_c\pi^+\pi^-)$
- $\eta_c \to K_S K\pi$, $K_S \to \pi^+\pi^-$
- Assumed width is the weighted mean of previously published measurements:
  - $\Gamma_{Z(3900)} = (35 \pm 7)$ MeV
  - $\Gamma_{Z(4020)} = (12 \pm 3)$ MeV

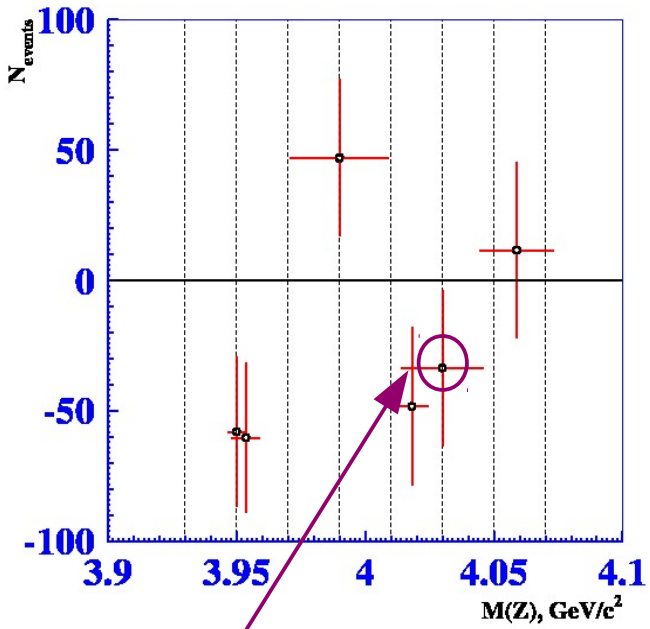
$Z(3900)^0$ & $Z(4020)^0$ (2)

Mass scan:

$Z(3900)^0$



$Z(4020)^0$



Masses closest to the corresponding charged partners

X(3915) (1)

Motivation:

In 2005 Belle observed Y(3940) in the decay to $J/\psi\omega$.
Another resonance X(3915) was first seen by BaBar, then confirmed by Belle in the same decay mode.
The mass of these particles is consistent and around 3918 MeV.

The nature of X(3915) is still undetermined (conventional charmonium, molecular state?).

$J^{PC} = 0^{++}$

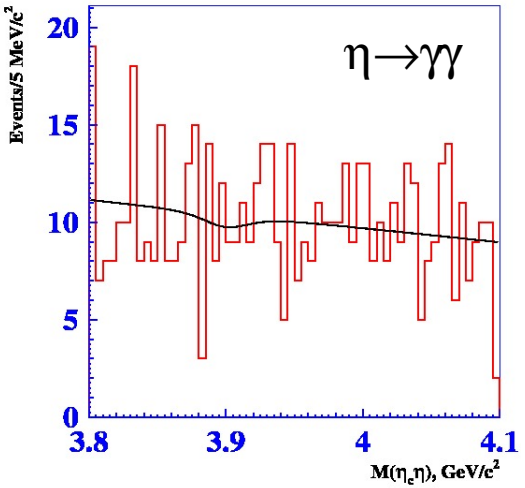
Analysis features:

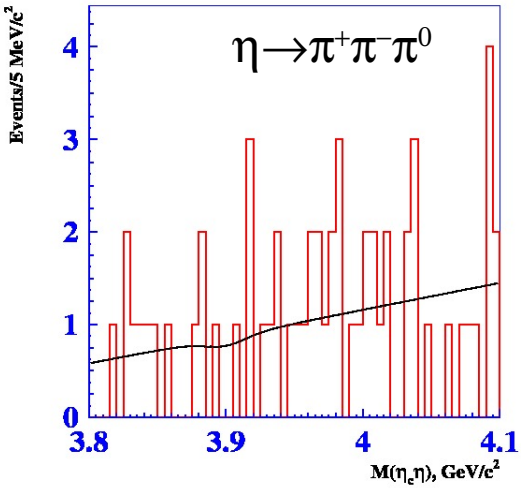
- X(3915) is produced in charged B decays: $B^{\pm} \to K^{\pm}X \to K^{\pm}(\eta_c\eta)$ and
  $B^{\pm} \to K^{\pm}X \to K^{\pm}(\eta_c\pi^0)$
- $\eta_c \to K_S K\pi$, $K_S \to \pi^+\pi^-$
- Assumed mass and width are the weighted mean of previous measurements:
  - $M = (3918.4 \pm 1.9)$ MeV
  - $\Gamma = (20 \pm 5)$ MeV

X(3915) (2)

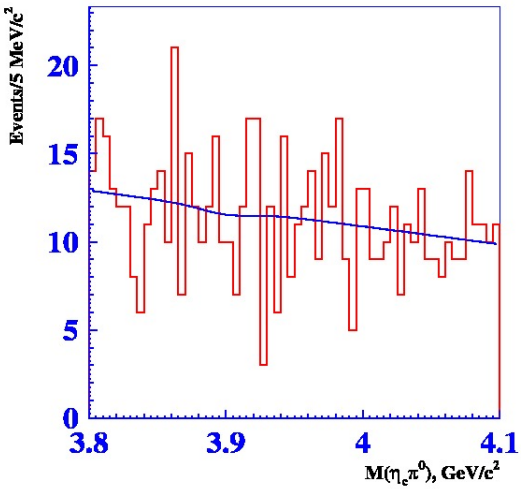
$X(3915) \to \eta_c \eta$

Combined fit:





$X(3915) \to \eta_c \pi^0$



Decay mode	Efficiency, %	Yield
$X(3915) \to \eta_c\eta$,		
$\eta \to \gamma\gamma$	6.60 ± 0.02	-7.4 ± 14.5
$\eta \to \pi^+\pi^-\pi^0$	1.64 ± 0.01	-1.1 ± 2.1
$X(3915) \to \eta_c\pi^0$	6.88 ± 0.02	-4.3 ± 18.1

Systematics

Additive for "X-like"

Source	$\eta_c\pi^+\pi^-$	$\eta_c\omega$	$\eta_c\eta$		$\eta_c\pi^0$	
X mass, MeV/c^2	3872	3872	3730	4014	3730	4014
Resolution degradation	1.2	—	68	28	1.4	0.2
Bg parametrization	5.8	3.6	18	8	0.8	0.3
Sel. criteria variation	23.9	5.4	293	280	5.2	9.3
Bin size	1.2	7.7	30	71	2.4	4.4
Total (events)	24.7	10.1	303	290	5.9	10.3

Additional systematics for $Z(3900)^0$

- Additive: ±14.4 from width scan [15 : 65] MeV ⇒ 28.6
- Multiplicative: ±15.9% from decay model variation ⇒ 15.9%

Additional systematics for $Z(4020)^0$

- Additive: ±7.8 from width scan [2.5 : 27.5] MeV ⇒ 25.9
- Multiplicative: ±4.4% from decay model variation ⇒ 9.7%

For X(3915) same as for X(4014)

Additive no resonance

Source	$\eta_c\pi^+\pi^-$	$\eta_c\omega$	$\eta_c\eta$	$\eta_c\pi^0$
Bg parametrization	1	44	2687	2.2
Sel. criteria variation	—	—	1695	32.6
Bin size	18	2	430	9.2
Total (events)	18	44	3206	33.9

Multiplicative

Source	$\eta_c\pi^+\pi^-$	$\eta_c\omega$	$\eta_c\eta$	$\eta_c\pi^0$
Number of $B\bar{B}$ pairs	1.4	1.4	1.4	1.4
$\mathcal{B}(\omega \to \pi^+\pi^-\pi^0)$	—	0.8	—	—
$\mathcal{B}(\pi^0 \to \gamma\gamma)$	—	< 0.1	< 0.1	< 0.1
$\mathcal{B}(\eta \to \gamma\gamma)$	—	—	0.5	—
$\mathcal{B}(\eta \to \pi^+\pi^-\pi^0)$	—	—	1.2	—
$\mathcal{B}(\eta_c \to K^0_S K^\pm\pi^\mp)$	6.8	6.8	6.8	6.8
$\mathcal{B}(K^0_S \to \pi^+\pi^-)$	0.1	0.1	0.1	0.1
MC detection efficiency				
no resonance	35.8	2.4	1.3	19.5
$X(3872)$-like	0.3	0.5	0.7	0.3
$Z(3900)^0/Z(4020)^0$	13.3/4.4	—	—	—
Track reconstruction	1.7	1.7	1.7	1.0
$K^\pm$ identification	1.6	1.6	1.6	1.6
$\pi^\pm$ identification	1.5	1.5	1.5	0.5
η reconstruction	—	—	2.0	—
π^0 reconstruction	—	2.0	2.0	2.0
K^0_S reconstruction	4.4	4.4	4.4	4.4
Total (%)				
no resonance	36.8	9.3	9.3	21.3
$X(3872)$-like	8.7	9.0	9.2	8.7
$Z(3900)^0/Z(4020)^0$	15.9/9.7	—	—	—

Results

Upper limits are set on the product branching fractions of production and decay of X and Z, also on the branching fractions of $B^{\pm}\to K^{\pm}\eta_c$ + hadrons.

B decays with intermediate resonances

Resonance	Decay mode	Upper limit (90% C.L.)
$X_1(3872)$	$\eta_c\pi^+\pi^-$	3.0×10^{-5}
	$\eta_c\omega$	6.9×10^{-5}
$X(3730)$	$\eta_c\eta$	4.6×10^{-5}
	$\eta_c\pi^0$	5.7×10^{-6}
$X(4014)$	$\eta_c\eta$	3.9×10^{-5}
	$\eta_c\pi^0$	1.2×10^{-5}
$Z(3900)^0$	$\eta_c\pi^+\pi^-$	4.7×10^{-5}
$Z(4020)^0$		1.6×10^{-5}
$X(3915)$	$\eta_c\eta$	3.3×10^{-5}
	$\eta_c\pi^0$	1.8×10^{-5}

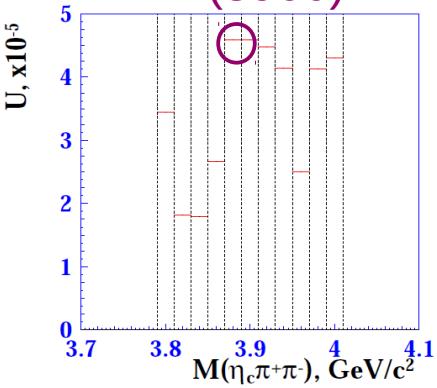
arXiv:1501.06351

submitted to JHEP

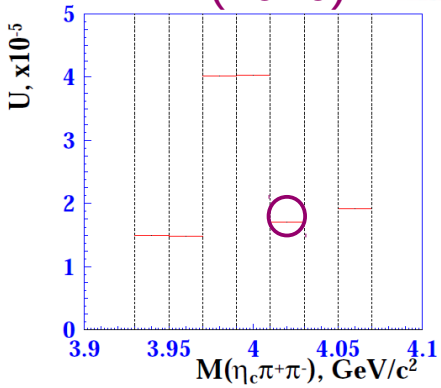
B decays without intermediate resonances

Decay mode	Upper limit (90% C.L.)
$B^{\pm}\to K^{\pm}\eta_c\pi^+\pi^-$	3.9×10^{-4}
$B^{\pm}\to K^{\pm}\eta_c\omega$	5.3×10^{-4}
$B^{\pm}\to K^{\pm}\eta_c\eta,$	2.2×10^{-4}
$B^{\pm}\to K^{\pm}\eta_c\pi^0$	6.2×10^{-5}

$Z^0(3900)$



$Z^0(4020)$



Summary

- Study of $B^{\pm}$ decays to different η_c modes ($K^{\pm}\eta_c\pi^+\pi^-$, $K^{\pm}\eta_c\omega$, $K^{\pm}\eta_c\eta$, and $K^{\pm}\eta_c\pi^0$) was performed.
- Upper limits on the branching fractions $\mathcal{B}(B^{\pm}\to K^{\pm}\eta_c+\text{hadrons})$ were obtained.
- Search for such exotic states as $D^{(*)}\overline{D}^{(*)}$ bound states ("X(3872)-like" particles), neutral partners of $Z(3900)^{\pm}$ and $Z(4020)^{\pm}$, and X(3915) was carried out.
- A test mode for the decay $B^{\pm}\to K^{\pm}X\to K^{\pm}(\eta_c\pi^+\pi^-)$ – $B^{\pm}\to K^{\pm}\psi(2S)\to K^{\pm}(J/\psi\pi^+\pi^-)$ – was studied. Measurement of the signal yield gave results consistent with the PDG data.
- No signal was observed in any of the studied decay channels. Upper limits were set on the corresponding product branching fractions $\mathcal{B}(B^{\pm}\to K^{\pm}X)\times\mathcal{B}(X\to\eta_c+\text{hadrons})$.
- A more copious data set expected from the upcoming Belle II experiment can provide an opportunity to determine these branching fractions.