Charmonium results at Belle

Kirill Chilikin

Lebedev Physical Institute of the Russian Academy of Sciences

for the Belle Collaboration

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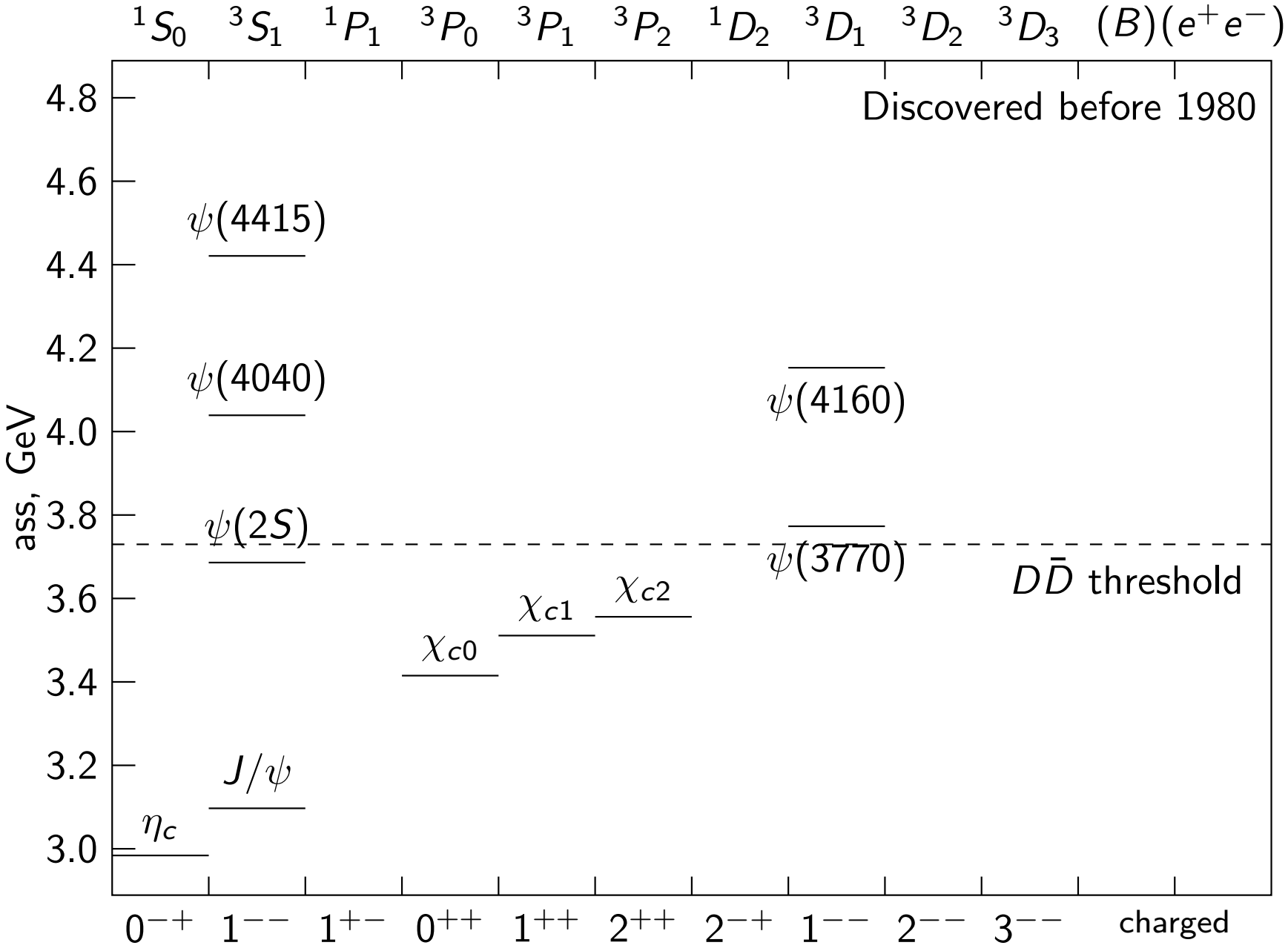
Outline

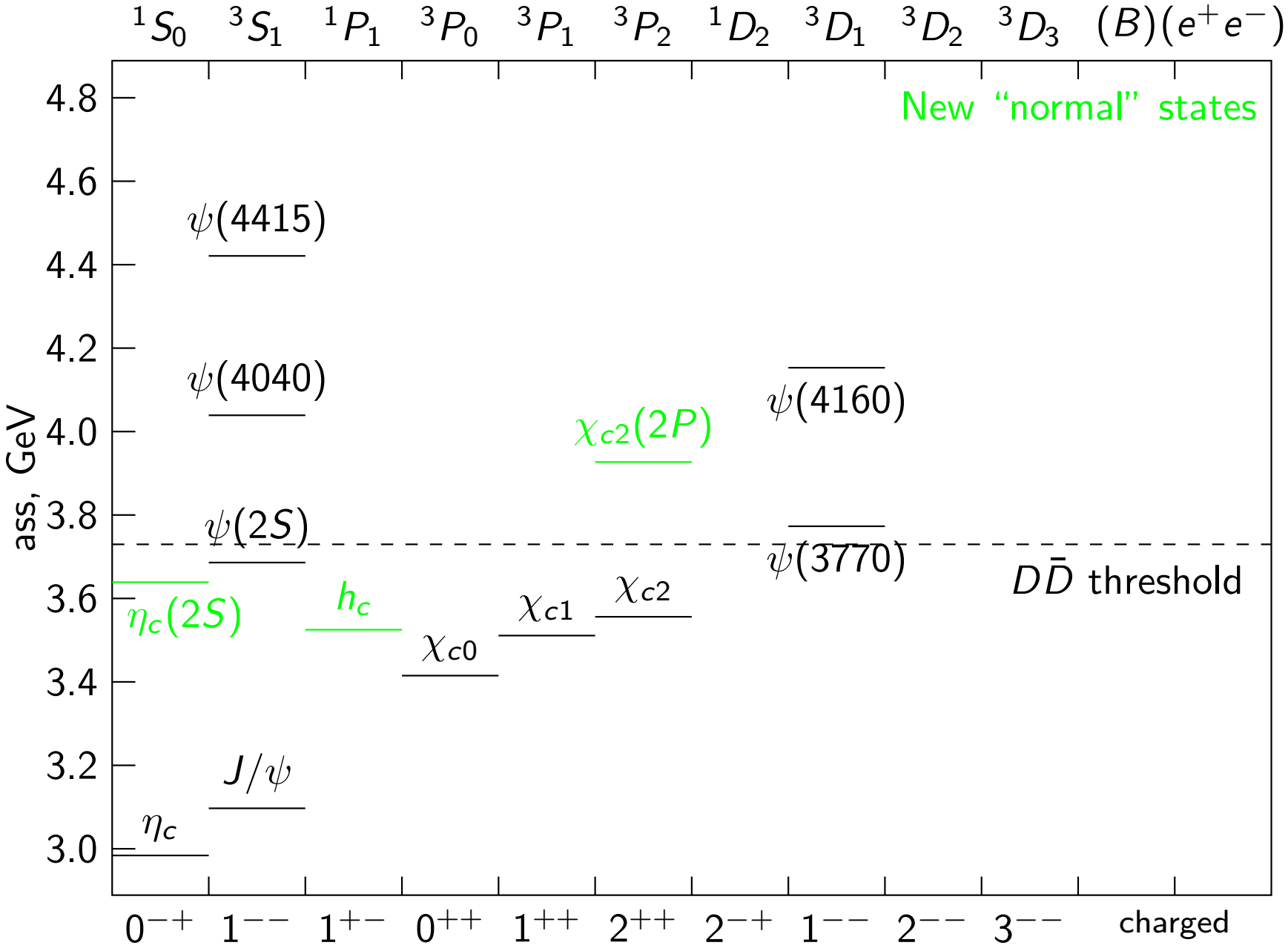
The following results will be presented:

- Search for B decays to final states with the η_c meson.
- Observation of $X(3872)$ in $B \to X(3872)K\pi$ decays.
- Measurement of $e^+e^- \to \chi_{cJ}\gamma$ via initial state radiation.
- Inclusive and exclusive measurements of B decays to χ_{c1} and χ_{c2}.
- Observation of $B^0 \to \psi(2S)\pi^0$.
- Search for charmoniumlike states in $\Upsilon(1S)$ decays.

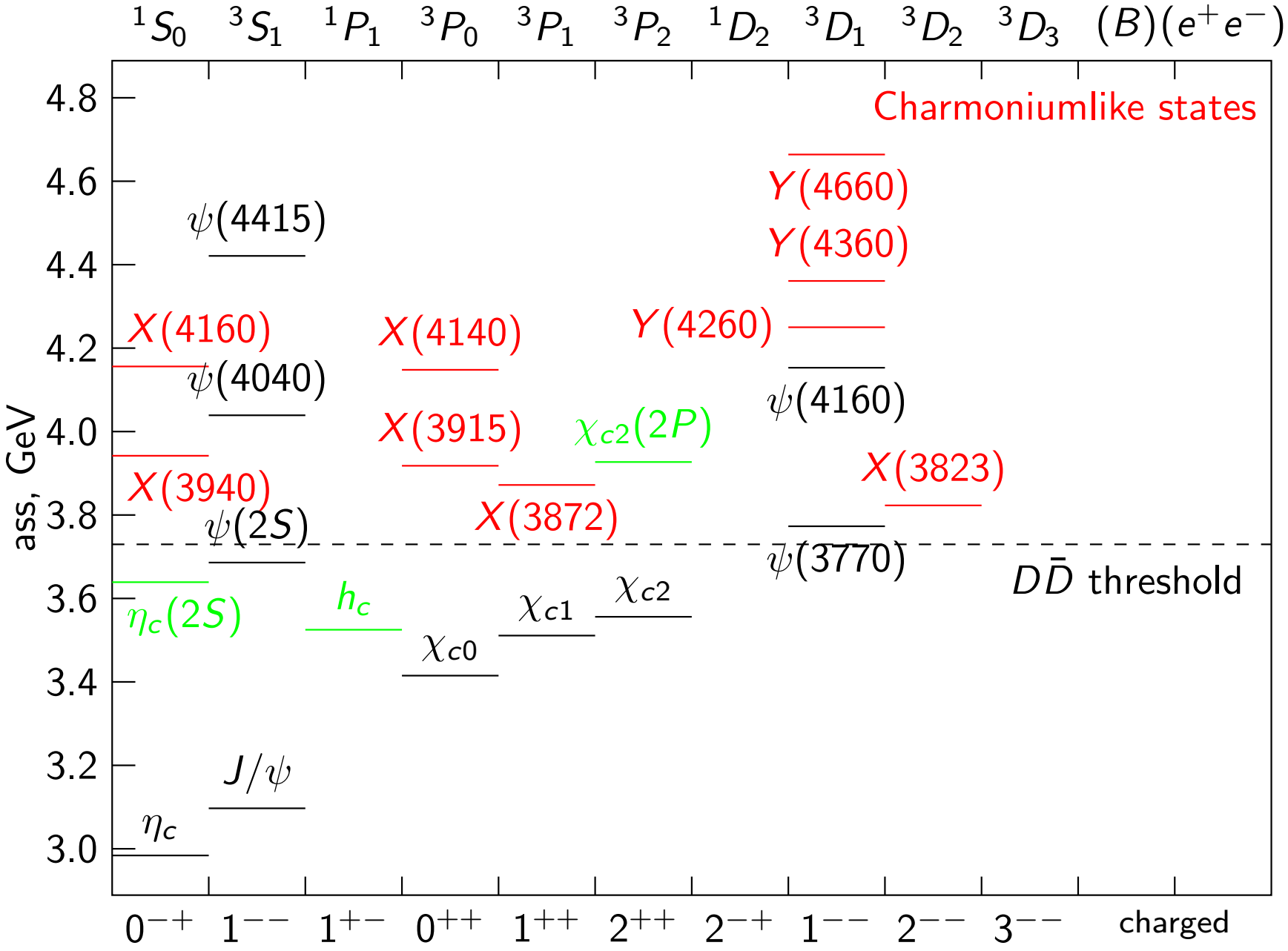
Charmonium states



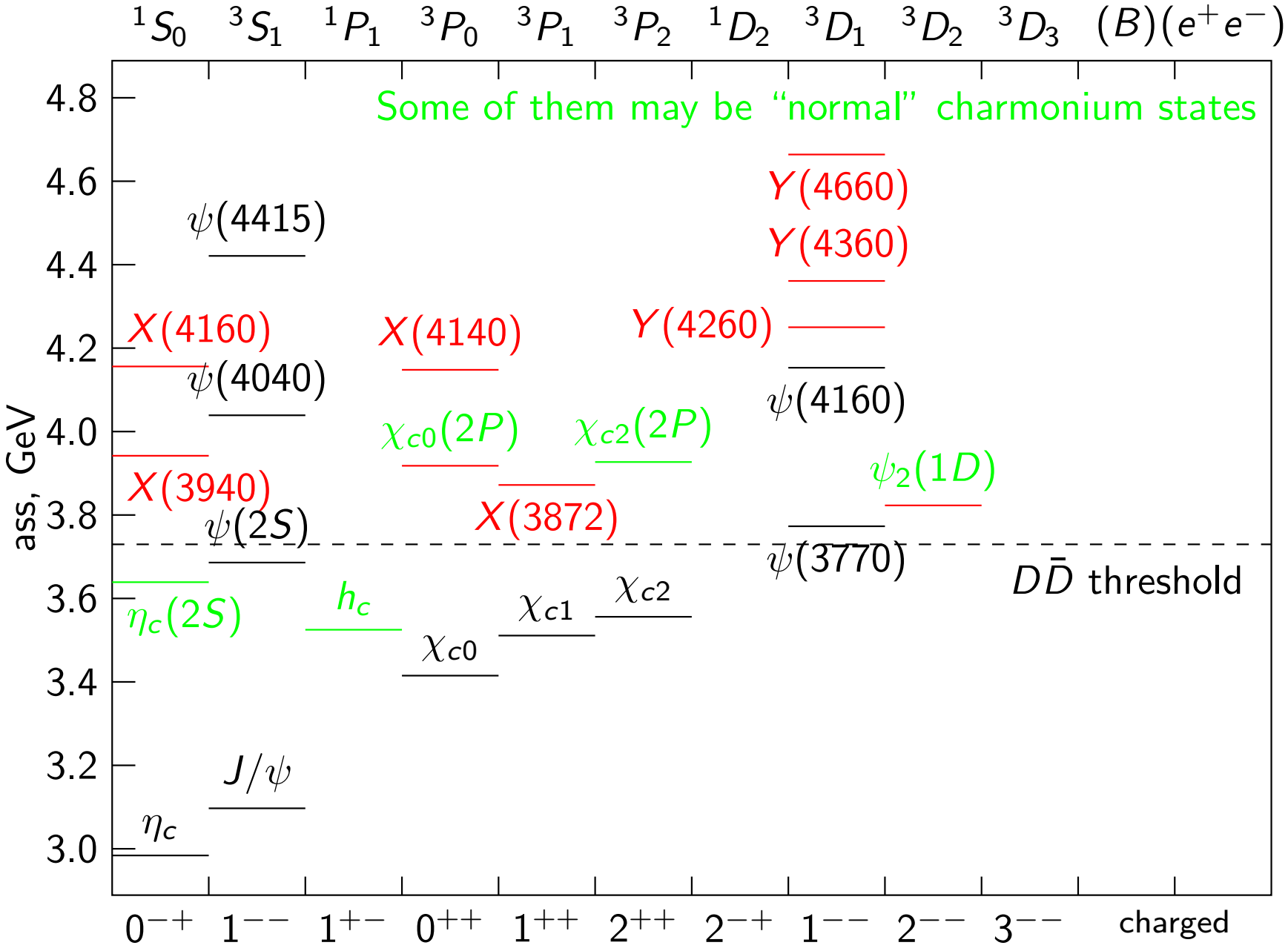
Charmonium states



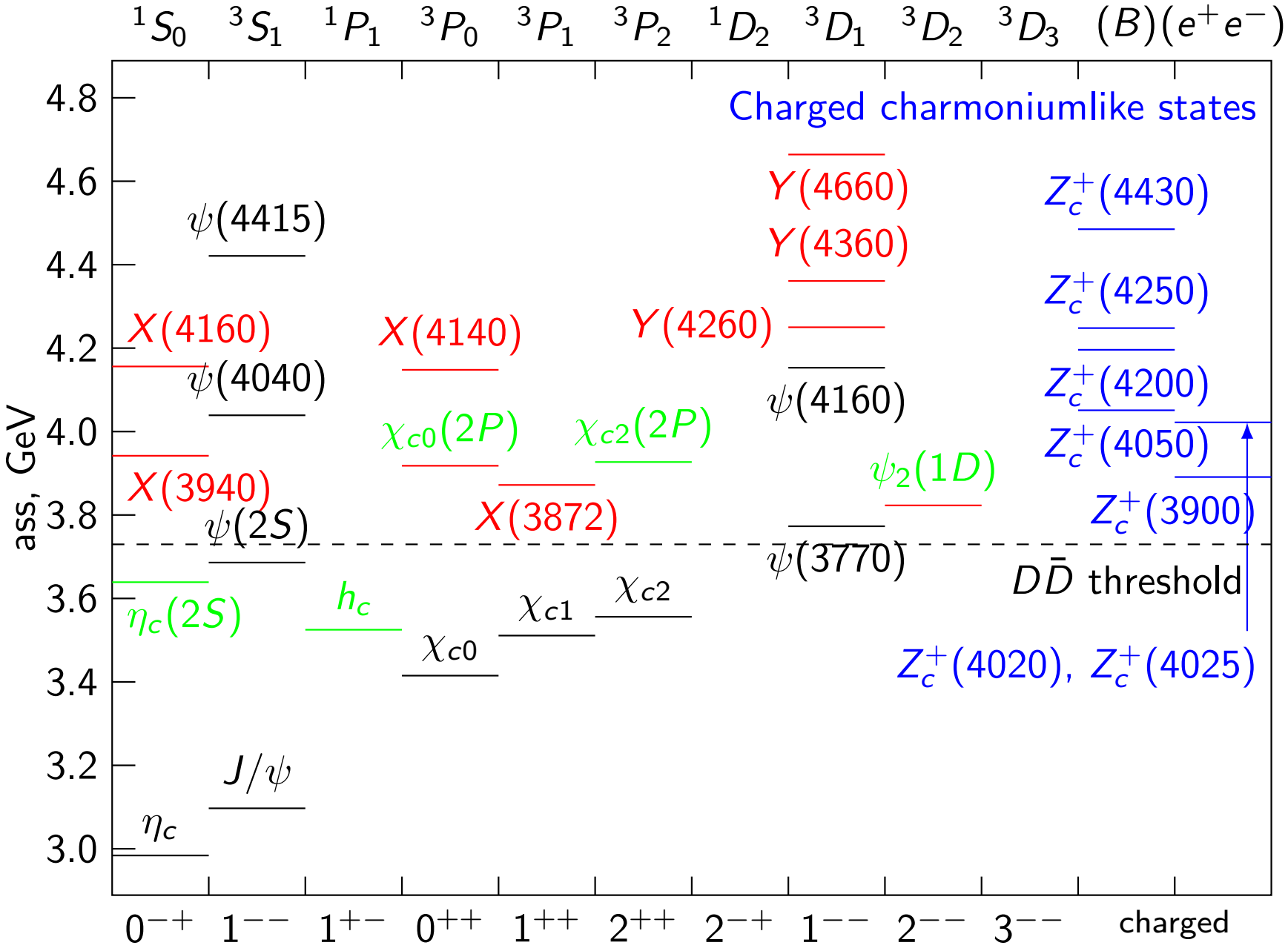
Charmonium states



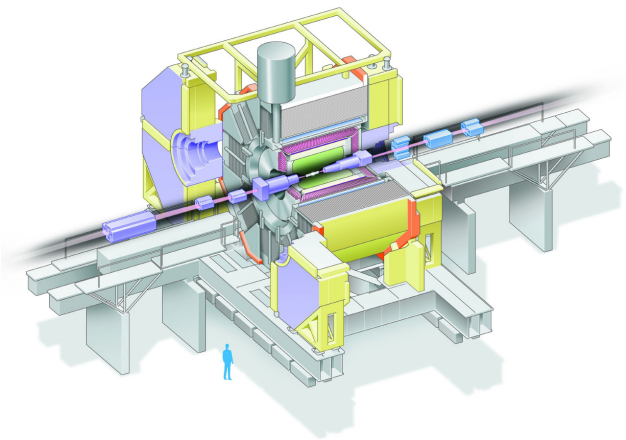
Charmonium states

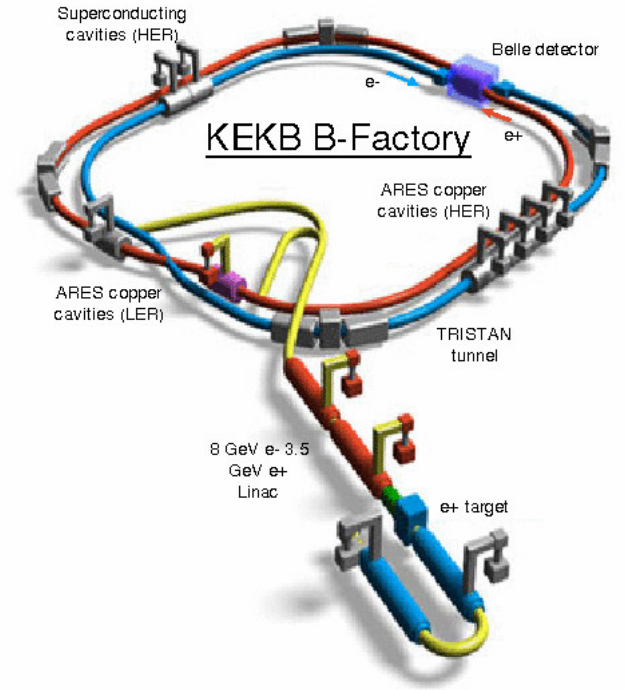


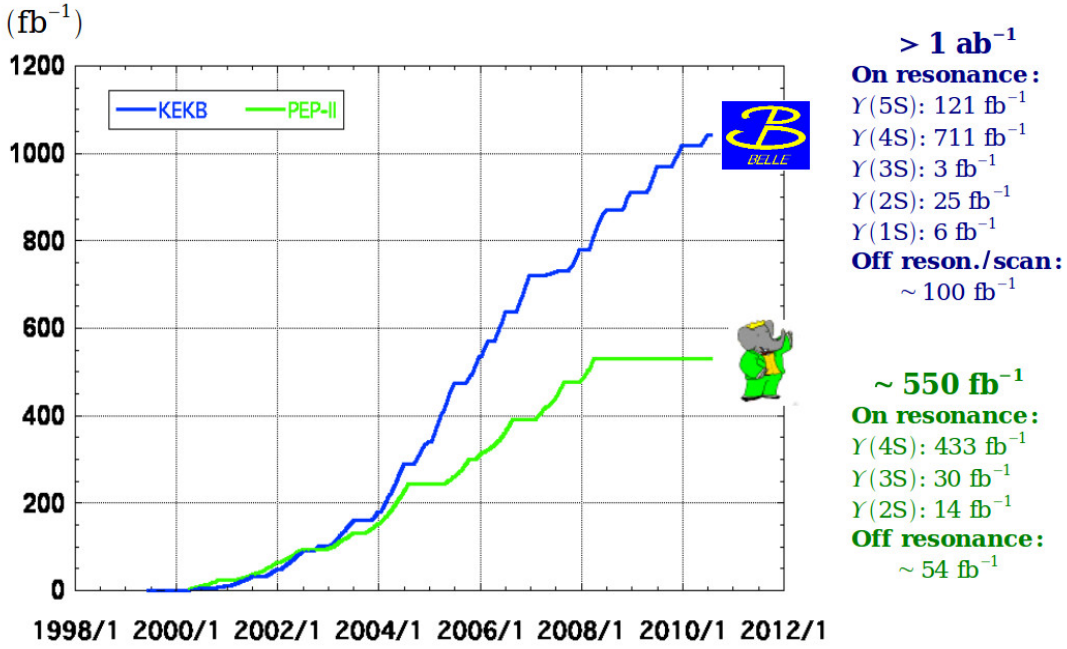
Charmonium states



The Belle experiment







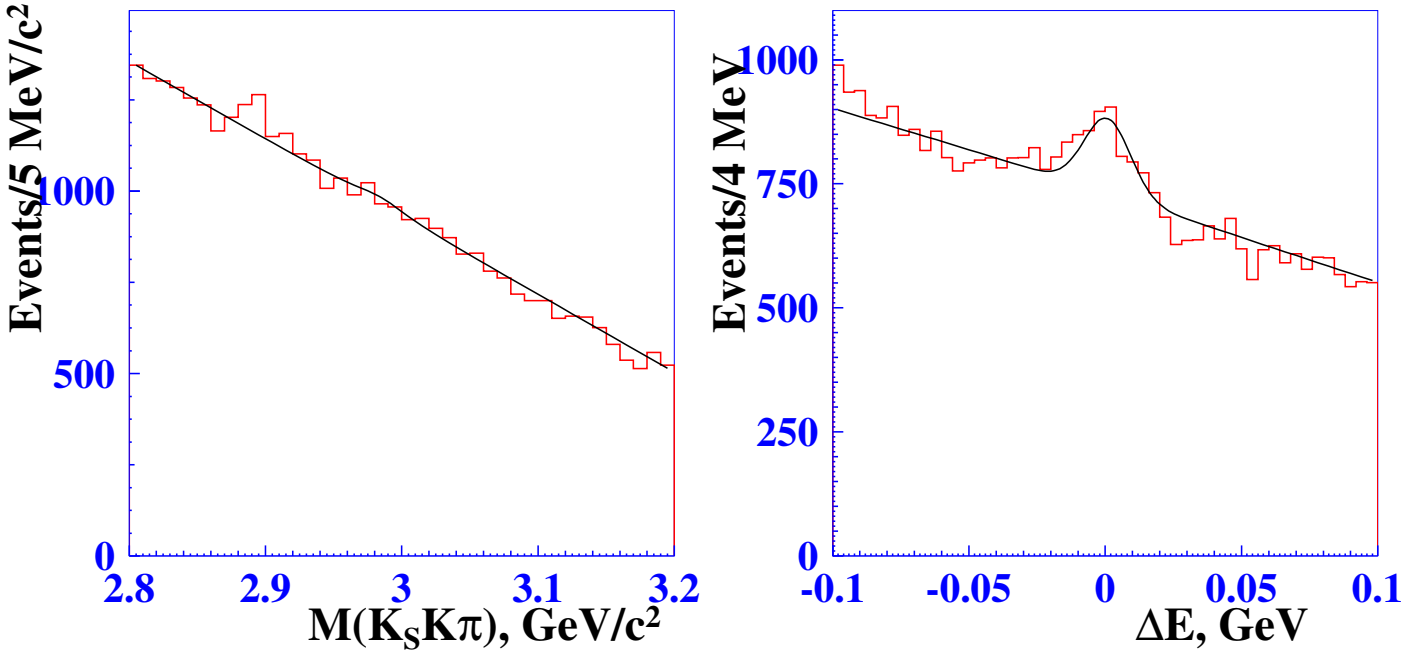
Charmonium production:

- B decays ($\Upsilon(4S)$ sample: 711 fb^{-1}, 772×10^6 B pairs)
- Initial state radiation ($\Upsilon(nS)$ sample: 980 fb^{-1}).
- $\Upsilon(1S)$ decays ($\Upsilon(1S)$ sample: 5.74 fb^{-1}).

Search for B decays to final states with the η_c meson

JHEP **1506**, 132 (2015)

Search for: $B^\pm \to K^\pm \eta_c \pi^+ \pi^-$, $B^\pm \to K^\pm \eta_c \omega$, $B^\pm \to K^\pm \eta_c \eta$, $B^\pm \to K^\pm \eta_c \pi^0$. No significant signal is found. Example ($B^\pm \to K^\pm \eta_c \pi^+ \pi^-$, $\eta_c \to K_S^0 K \pi$):



Branching fraction upper limits (90% CL): $B^\pm \to K^\pm \eta_c \pi^+ \pi^-$: 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}.

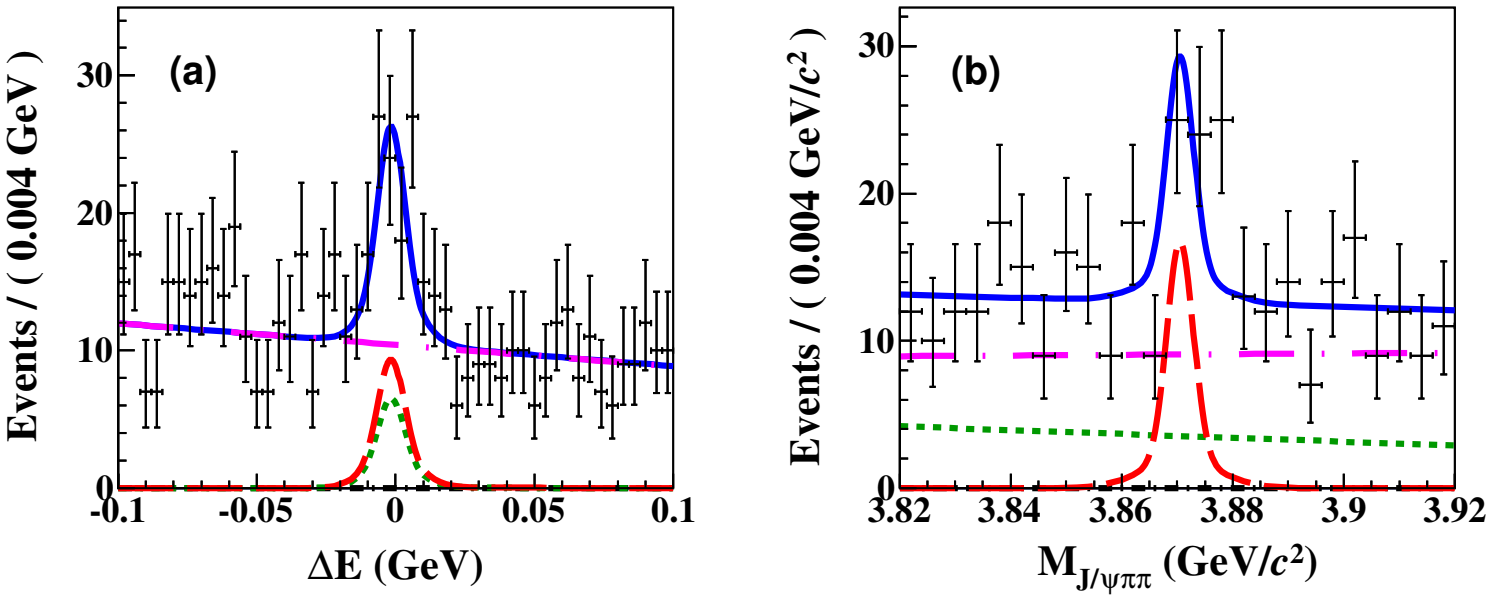
Search for B decays to final states with the η_c meson

Searches for decays via known charmoniumlike states and hypothetical $D\bar{D}$ molecular state $X(3730)$ were also preformed. There are no significant signals. Branching fraction product limits:

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}

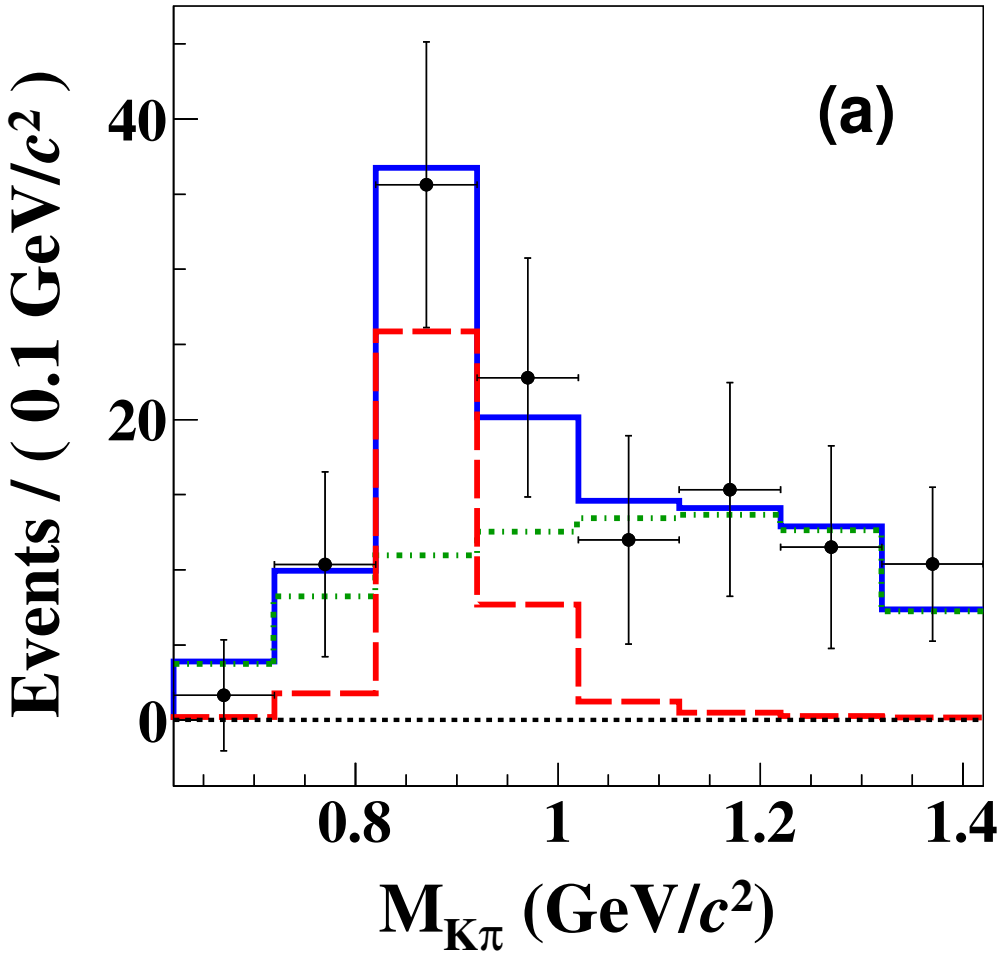
Observation of $X(3872)$ in $B \to X(3872)K\pi$ decays

Phys. Rev. D **91**, 051101 (2015)



$\mathcal{B}(B^0 \to X(3872)K^+\pi^-) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) =$
$(7.9 \pm 1.3 \pm 0.4) \times 10^{-6}$, significance: 7.0σ (first observation).
$\mathcal{B}(B^+ \to X(3872)K^0\pi^+) \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) =$
$(10.6 \pm 3.0 \pm 0.9) \times 10^{-6}$, significance: 3.7σ (first evidence).

Observation of $X(3872)$ in $B \to X(3872)K\pi$ decays

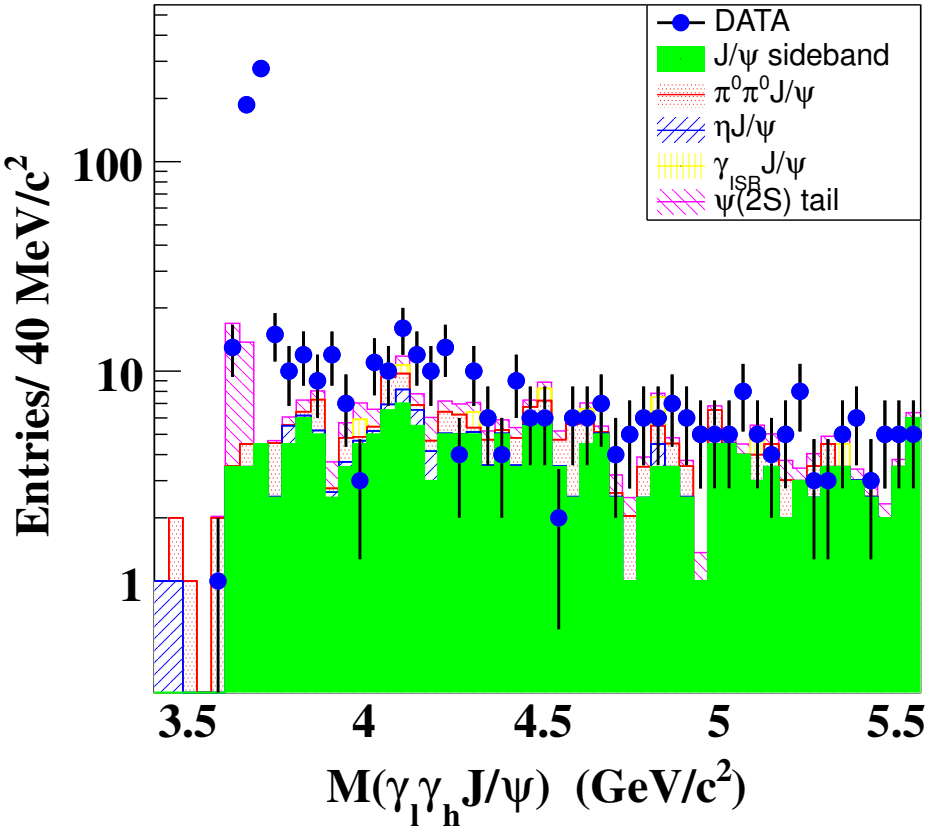


Fraction of the $K^*(892)$ is $0.34 \pm 0.09 \pm 0.02$.

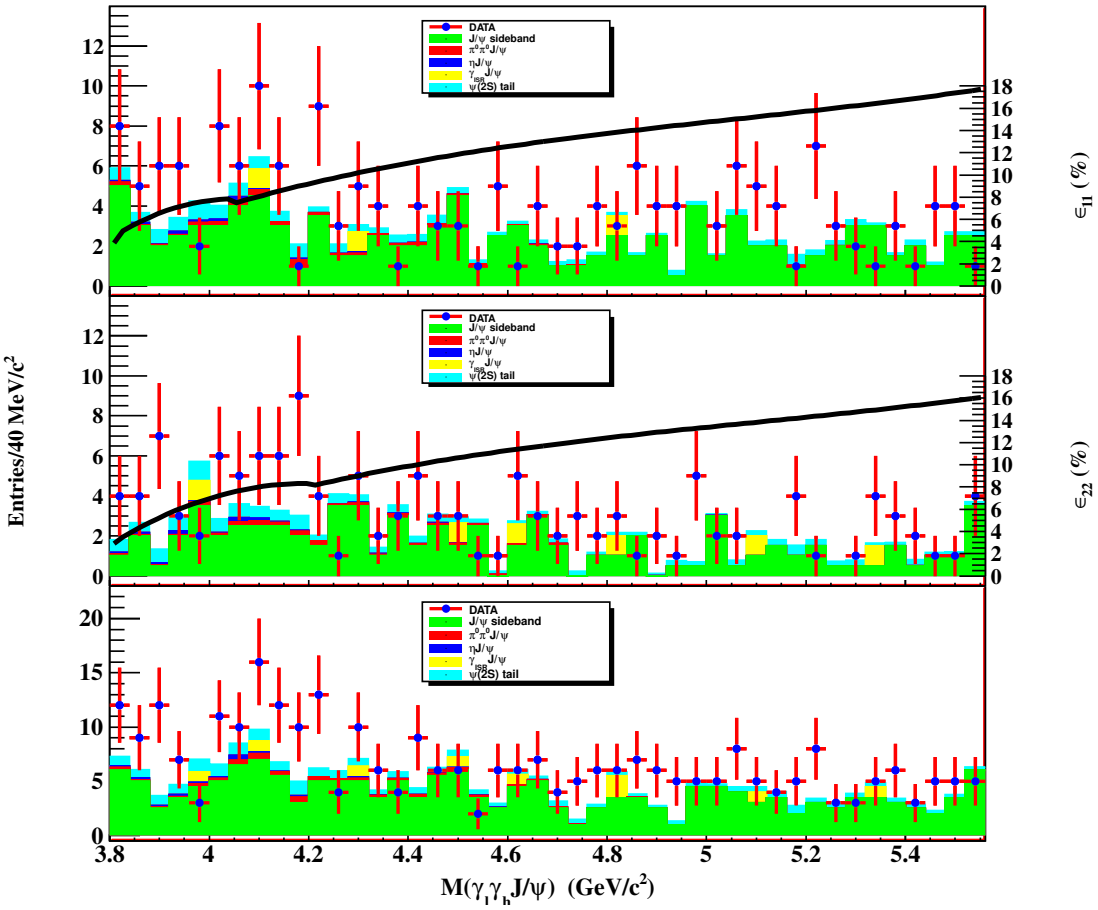
Measurement of $e^+e^- \to \chi_{cJ}\gamma$ via ISR

Phys. Rev. D **92**, 012001 (2015)

Search for the process $e^+e^- \to \chi_{cJ}\gamma\gamma_{\rm ISR}$ (radiative transitions from $Y(4260)$, $Y(4360)$, $Y(4660)$?). No significant signal is observed except from the $\psi(2S)$ decays.



Measurement of $e^+e^- \to \chi_{cJ}\gamma$ via ISR

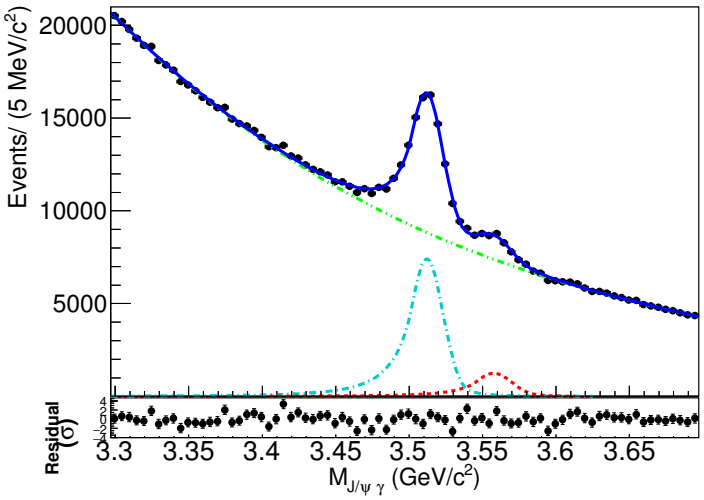


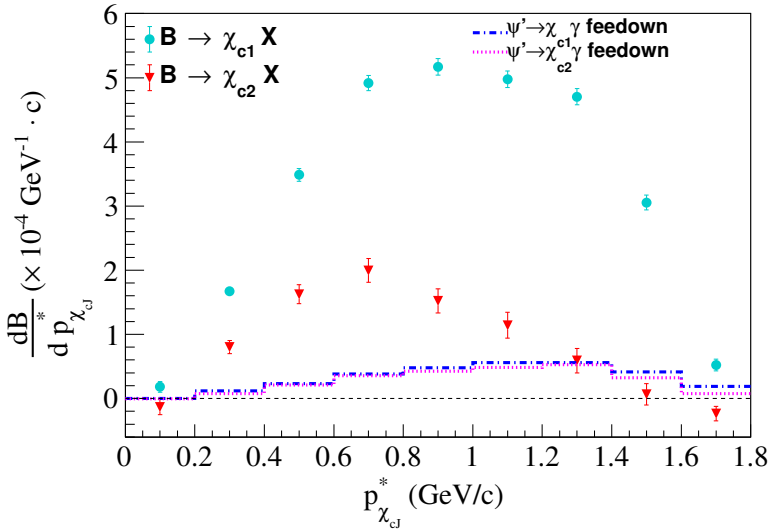
Invariant mass distributions: $\chi_{c1}\gamma$, $\chi_{c2}\gamma$ and combined. Cross section upper limits are set for each bin (4 - 134 pb at 90% CL).

B decays to χ_{c1} and χ_{c2}

Phys. Rev. D **93**, 052016 (2016)

Inclusive χ_{cJ} signal, $\Upsilon(4S)$ data - scaled off-resonance data





Feeddown events from $\psi(2S)$ are subtracted using results from Phys. Rev. D **67**, 032002 (2003). Branchings with feeddown:

$\mathcal{B}(B \to \chi_{c1}X) = (3.33 \pm 0.05 \pm 0.24) \times 10^{-3}$,

$\mathcal{B}(B \to \chi_{c2}X) = (0.98 \pm 0.06 \pm 0.10) \times 10^{-3}$.

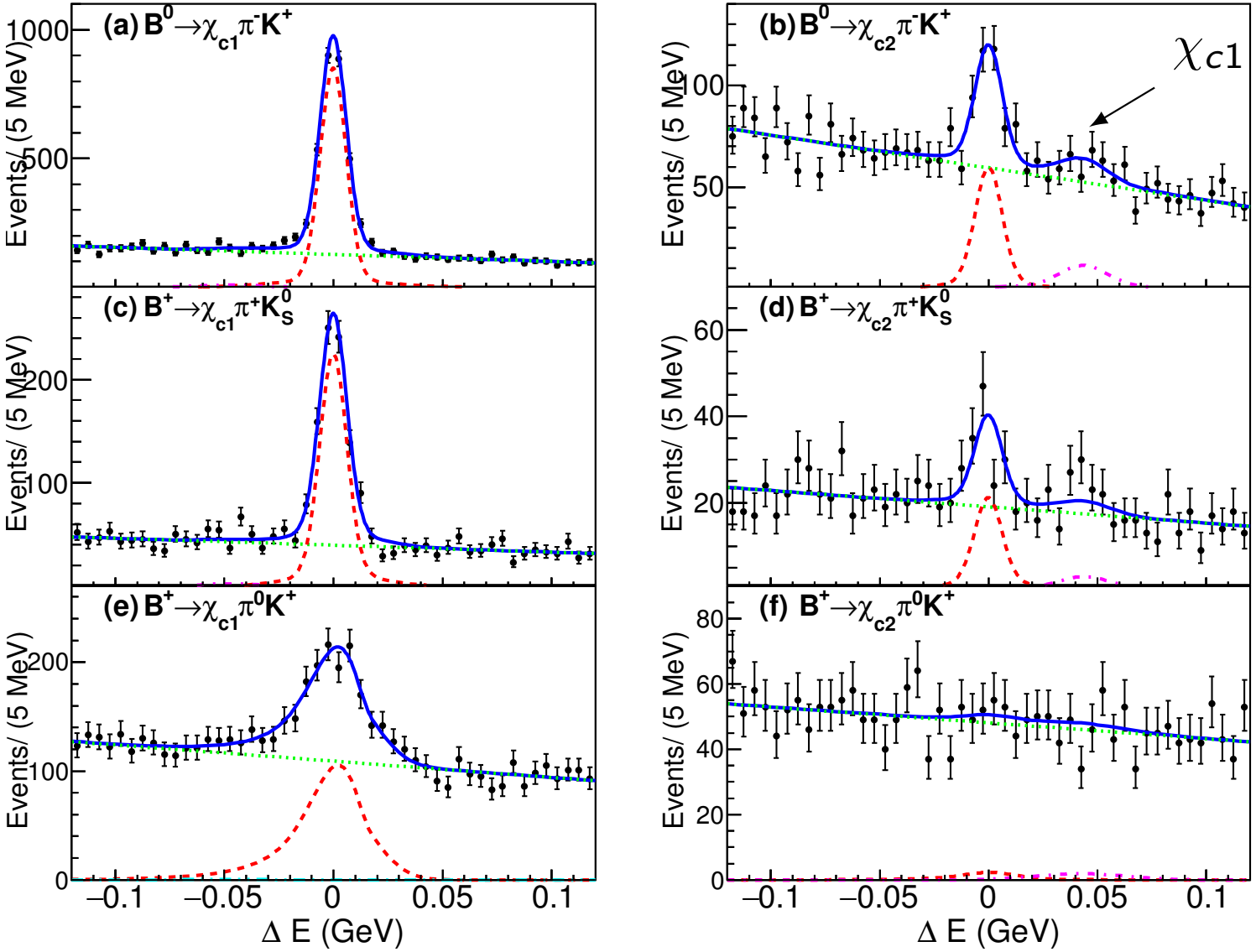
Branchings without feeddown:

$\mathcal{B}(B \to \chi_{c1}X) = (3.03 \pm 0.05 \pm 0.24) \times 10^{-3}$,

$\mathcal{B}(B \to \chi_{c2}X) = (0.70 \pm 0.06 \pm 0.10) \times 10^{-3}$.

B decays to χ_{c1} and χ_{c2}

Branching fractions of exclusive dfecay channels are also measured.



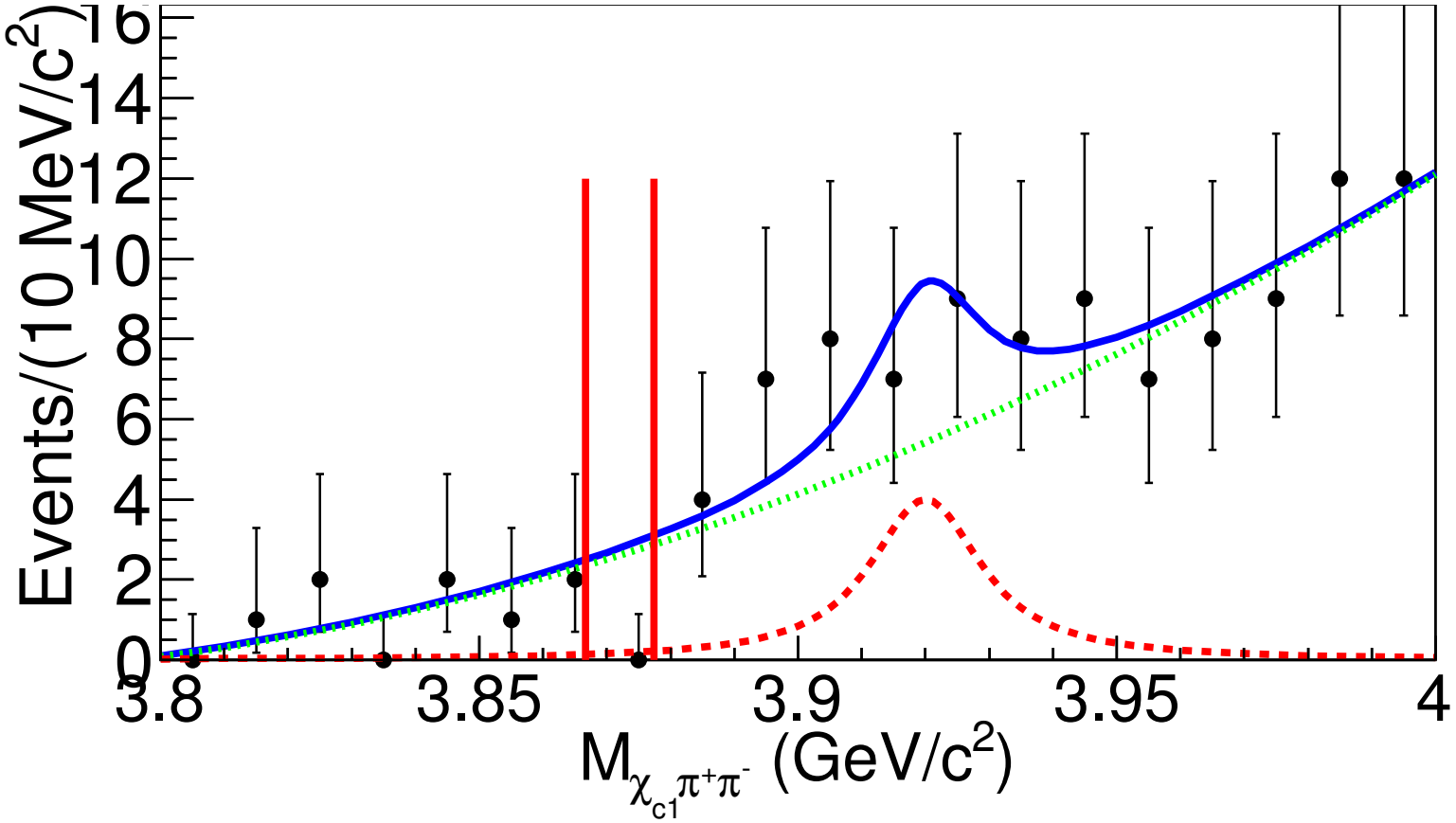
B decays to χ_{c1} and χ_{c2}

Branching fractions: results.

Decay	Yield (Y)	$\mathcal{S}(\sigma)$	$\epsilon(\%)$	$\mathcal{B}$ (10^{-4})	$\mathcal{R}_{\mathcal{B}}$
$B^0 \to \chi_{cJ}\pi^- K^+$					0.14 ± 0.02
χ_{c1}	2774 ± 66	66.7	17.9	$4.97 \pm 0.12 \pm 0.28$	
χ_{c2}	206 ± 25	8.7	16.2	$0.72 \pm 0.09 \pm 0.05$	
$B^+ \to \chi_{cJ}\pi^+ K^0$					0.20 ± 0.04
χ_{c1}	770 ± 35	33.7	8.6	$5.75 \pm 0.26 \pm 0.32$	
χ_{c2}	76.4 ± 14.7	4.6	7.5	$1.16 \pm 0.22 \pm 0.12$	
$B^+ \to \chi_{cJ}\pi^0 K^+$					< 0.21
χ_{c1}	803 ± 70	15.6	7.8	$3.29 \pm 0.29 \pm 0.19$	
χ_{c2}	17.5 ± 28.4	0.4	7.0	< 0.62	
$B^+ \to \chi_{cJ}\pi^+\pi^- K^+$					0.36 ± 0.05
χ_{c1}	1502 ± 70	19.2	12.8	$3.74 \pm 0.18 \pm 0.24$	
χ_{c2}	269 ± 34	8.4	11.4	$1.34 \pm 0.17 \pm 0.09$	
$B^0 \to \chi_{cJ}\pi^+\pi^- K^0$					< 0.61
χ_{c1}	268 ± 30	7.1	5.4	$3.16 \pm 0.35 \pm 0.32$	
χ_{c2}	37.8 ± 14.2	1.8	4.8	< 1.70	
$B^0 \to \chi_{cJ}\pi^-\pi^0 K^+$					< 0.25
χ_{c1}	545 ± 81	6.5	5.0	$3.52 \pm 0.52 \pm 0.24$	
χ_{c2}	-76.7 ± 42.0	—	4.3	< 0.74	

B decays to χ_{c1} and χ_{c2}

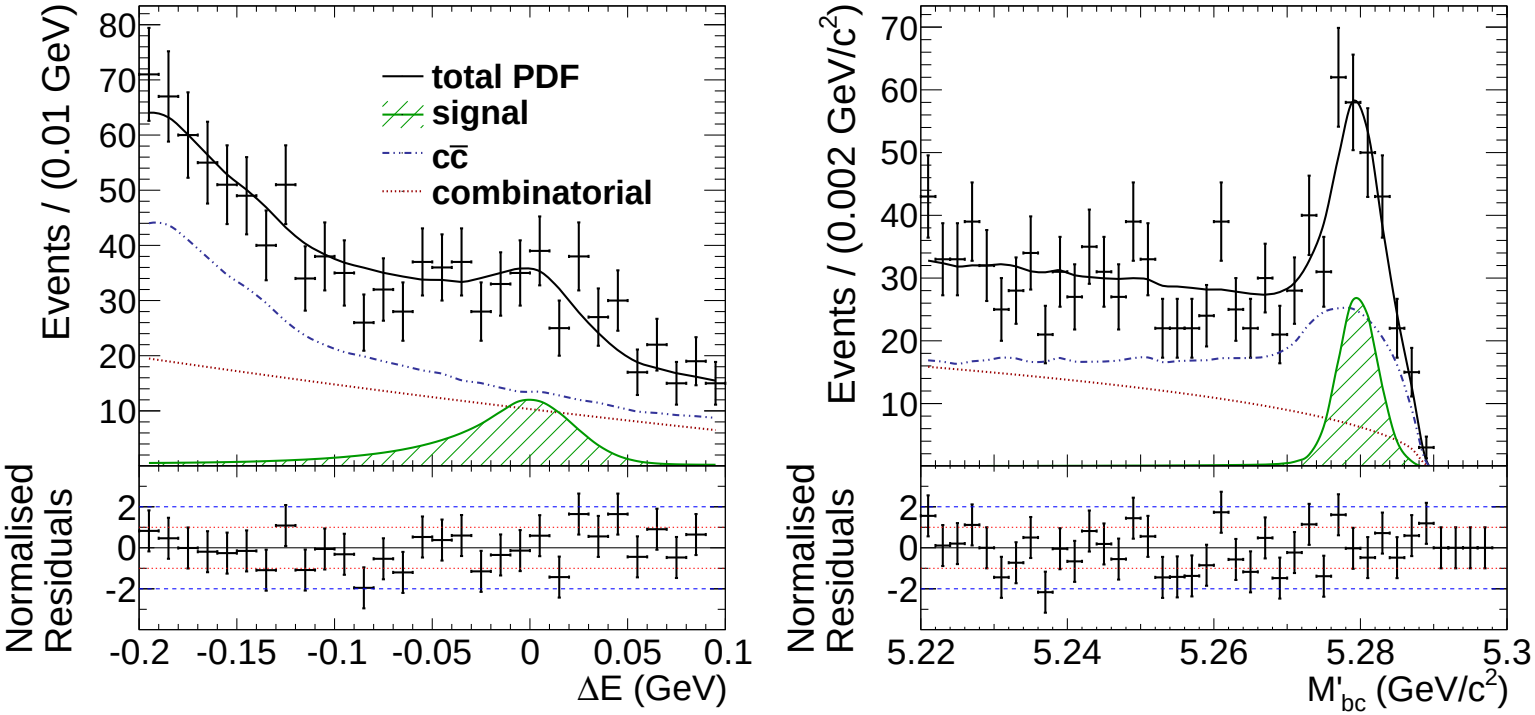
Search for new states decaying to $\chi_{c1}\pi^+\pi^-$ ($\chi_{c1}(2P)$).



No significant signal. With $M = 3920$ MeV$/c^2$, $\Gamma = 20$ MeV$/c^2$, yield is 12.2 ± 9.1 events
$[\mathcal{B}(B^+ \to \chi_{c1}(2P)K^+)\mathcal{B}(\chi_{c1}(2P) \to \chi_{c1}\pi^+\pi^-) < 1.1 \times 10^{-5}$ (90% CL)].

Observation of $B^0 \to \psi(2S)\pi^0$

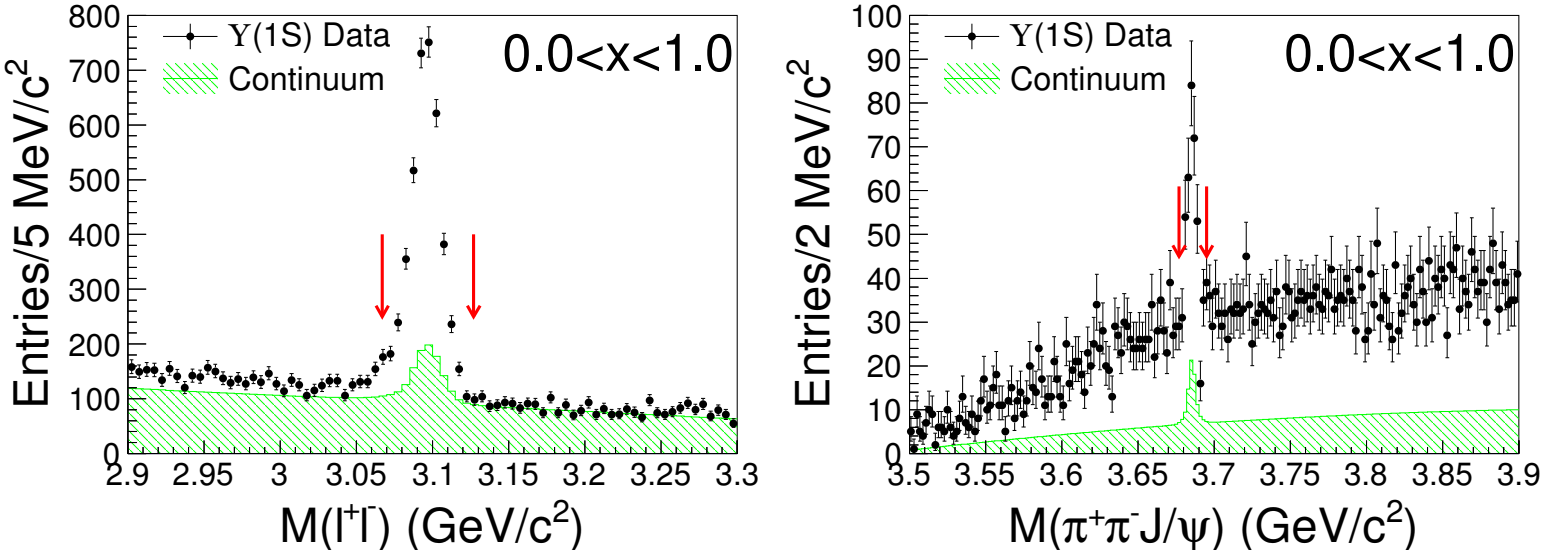
Phys. Rev. D **93**, 031101 (2016)



First observation of $B^0 \to \psi(2S)\pi^0$, significance: 7.2σ. Branching fraction: $\mathcal{B}(B^0 \to \psi(2S)\pi^0) = (1.17 \pm 0.17 \pm 0.08) \times 10^{-3}$.
This decay may be used to get higher-order correction to CKM angle ϕ_1/β [see Phys. Rev. Lett. **95**, 221804 (2005)].

Search for charmoniumlike states in $\Upsilon(1S)$ decays

arxiv:1605.00990



Branching fractions (X = anything):

$\mathcal{B}(\Upsilon(1S) \to J/\psi X) = (5.25 \pm 0.13 \pm 0.25) \times 10^{-4}$,

$\mathcal{B}(\Upsilon(1S) \to \psi(2S) X) = (1.23 \pm 0.17 \pm 0.11) \times 10^{-4}$.

Search for charmoniumlike states is performed, no significant signal is found.

Search for charmoniumlike states in $\Upsilon(1S)$ decays

State	$N_{\rm fit}$	Branching fraction limit
$X(3872) \to \pi^+\pi^- J/\psi$	4.8 ± 15.4	$< 9.5 \times 10^{-6}$
$Y(4260) \to \pi^+\pi^- J/\psi$	-31.1 ± 88.9	$< 3.8 \times 10^{-5}$
$Y(4260) \to \pi^+\pi^- \psi(2S)$	6.7 ± 29.4	$< 7.9 \times 10^{-5}$
$Y(4360) \to \pi^+\pi^- \psi(2S)$	-25.4 ± 30.1	$< 5.2 \times 10^{-5}$
$Y(4660) \to \pi^+\pi^- \psi(2S)$	-55.0 ± 26.2	$< 2.2 \times 10^{-5}$
$Y(4260) \to K^+K^- J/\psi$	-13.7 ± 10.9	$< 7.5 \times 10^{-6}$
$Y(4140) \to \phi J/\psi$	-0.1 ± 1.2	$< 5.2 \times 10^{-6}$
$X(4350) \to \phi J/\psi$	2.3 ± 2.5	$< 8.1 \times 10^{-6}$
$Z_c(3900)^\pm \to \pi^\pm J/\psi$	-26.5 ± 39.1	$< 1.3 \times 10^{-5}$
$Z_c(4200)^\pm \to \pi^\pm J/\psi$	-238.6 ± 154.2	$< 6.0 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm J/\psi$	94.2 ± 71.4	$< 4.9 \times 10^{-5}$
$Z_c(4050)^\pm \to \pi^\pm \psi(2S)$	37.0 ± 47.7	$< 8.8 \times 10^{-5}$
$Z_c(4430)^\pm \to \pi^\pm \psi(2S)$	23.2 ± 42.4	$< 6.7 \times 10^{-5}$
$Z_{cs}^\pm \to K^\pm J/\psi$	-22.2 ± 17.4	$< 5.7 \times 10^{-6}$

Summary

- Search for B decays to final states with the η_c meson is performed.
- The decay $B \to X(3872)K\pi$ is observed.
- No significant $e^+e^- \to \chi_{cJ}\gamma\gamma_{\mathrm{ISR}}$ except via $\psi(2S)$.
- Study of B decays to χ_{c1} and χ_{c2} is performed.
- The decay $B^0 \to \psi(2S)\pi^0$ is observed for the first time.
- No charmoniumlike states in $\Upsilon(1S)$ decays.