Recent results on charmonium states and search for pentaquark at Belle

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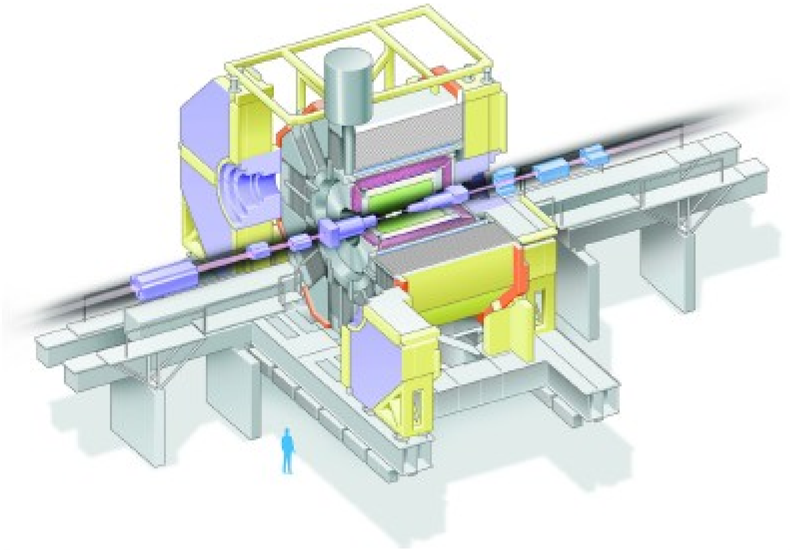
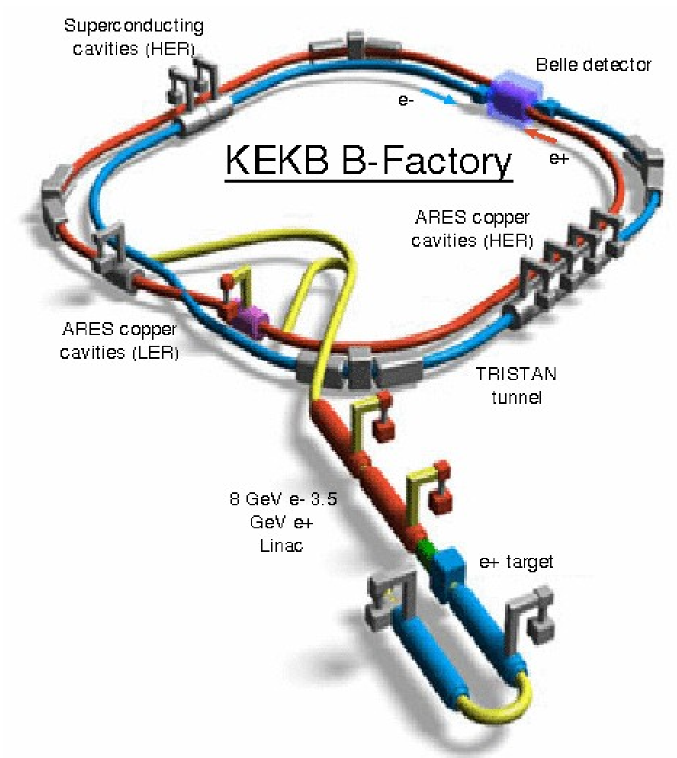
Outline:

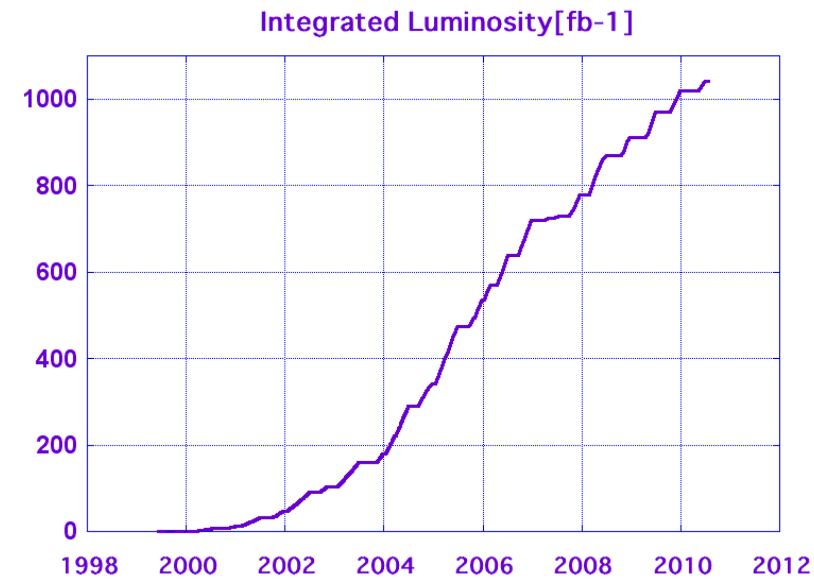
- Introduction
- Observation of $\chi_{c0}(2P)$ candidate in $e^+e^- \to J/\psi D\overline{D}$
- Measurement of the branching fractions of $B^+ \to X_{cc} K^+$ decays
- Search for hidden-strangeness pentaquark decay $P_s^+ \to \varphi p$ in $\Lambda_c \to \varphi p \pi^0$.

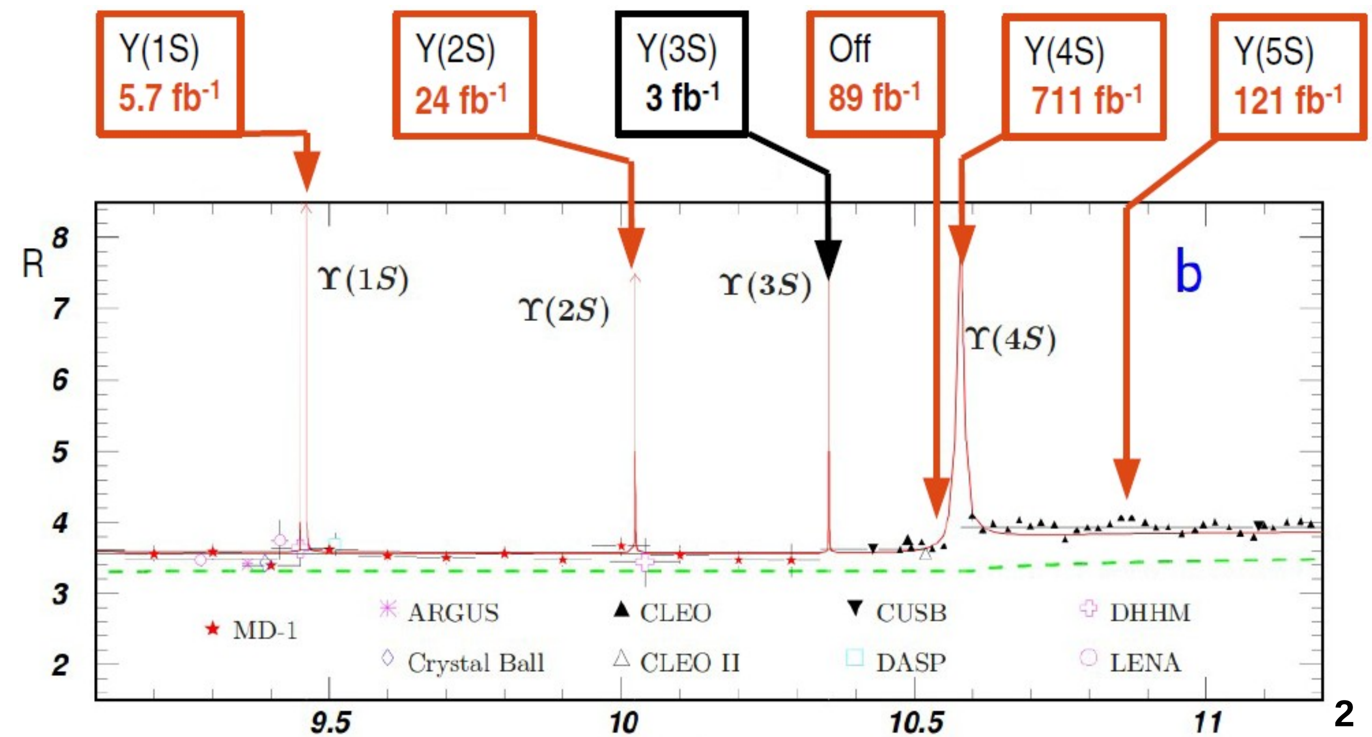
Summary

The Belle experiment









Observation of $\chi_{c0}(2P)$ in $e^+e^- \to J/\psi D\bar{D}$

BELLE

X(3915) was observed by the Belle in $B \to J/\psi\, \omega\, K$ decays. J^{PC} is measured to be 0^{++}. As a result, it was identified as the $\chi_{c0}(2P)$ in PDG 2014.

Doubts: expected main decay $\chi_{c0}(2P) \to D\bar{D}$ in an S-wave.

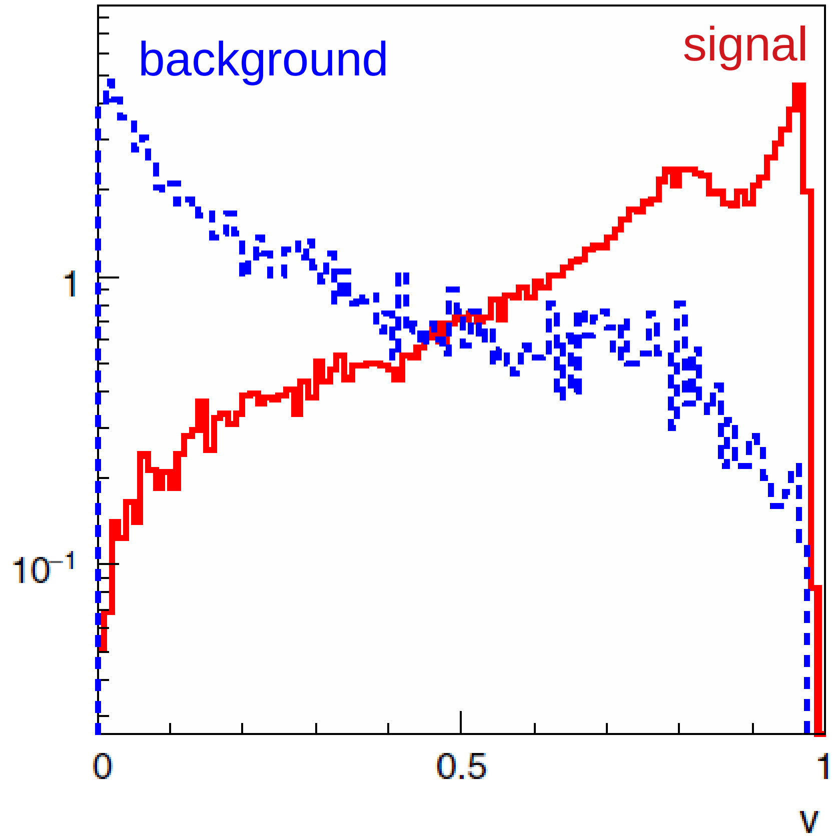
We search for $e^+e^- \to J/\psi\, \chi_{c0}(2P)$ with $\chi_{c0}(2P) \to D\bar{D}$

Only J/ψ and one of the D mesons are reconstructed; the other $\bar{D}$ meson is identified by the recoil mass of the $J/\psi D$ system.

Reconstructed channels:

- $D^+ \to K^0_S\pi^+$, $K^-\pi^+\pi^+$, $K^0_S\pi^+\pi^0$, $K^-\pi^+\pi^+\pi^0$, and $K^0_S\pi^+\pi^+\pi^-$.
- $D^0 \to K^-\pi^+$, $K^0_S\pi^+\pi^-$, $K^-\pi^+\pi^0$, and $K^-\pi^+\pi^+\pi^-$.
- $J/\psi \to e^+e^-$, $\mu^+\mu^-$.

Multivariable analysis to suppress background.



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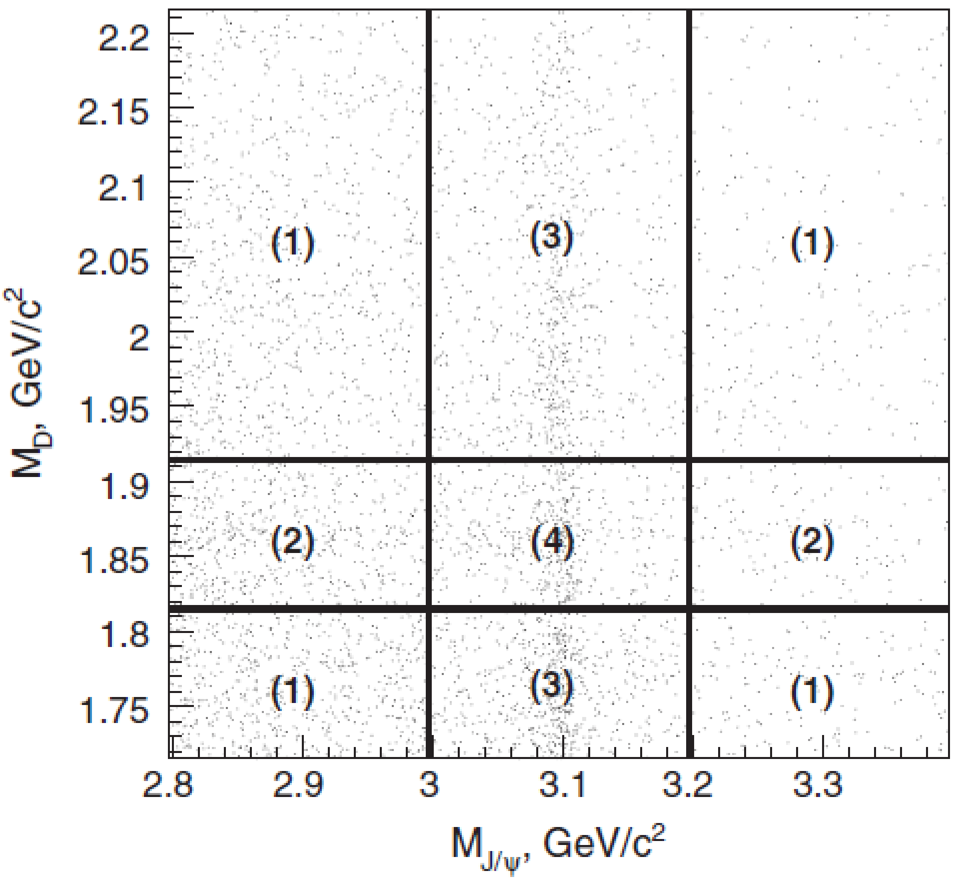
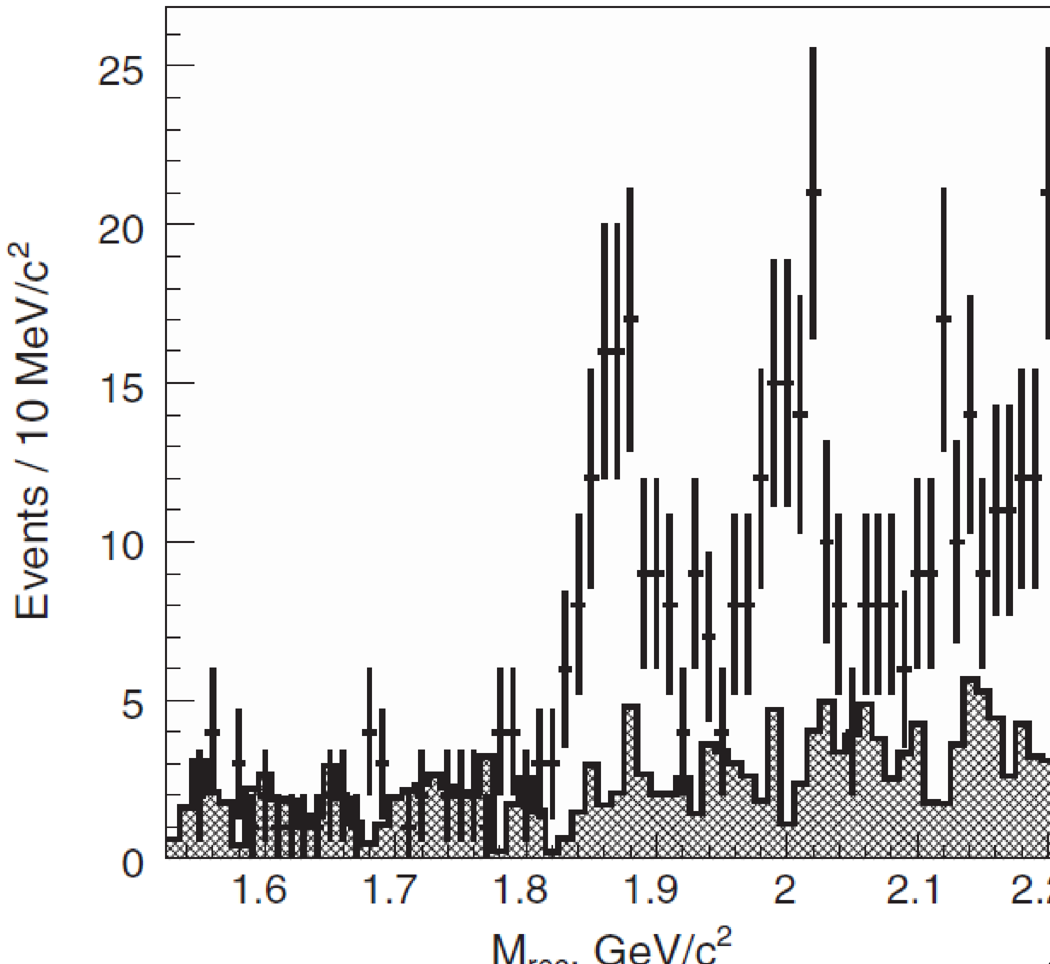
Observation of $\chi_{c0}(2P)$ in $e^+e^- \to J/\psi D\bar{D}$



Background contribution is estimated using J/ψ and D invariant masses:

(1) – pure combinatorial background
(2) – real D, combinatorial J/ψ
(3) – real J/ψ, combinatorial D
(4) – signal



Signal yield is extracted from the fit to the recoil mass to J/ψ D combination

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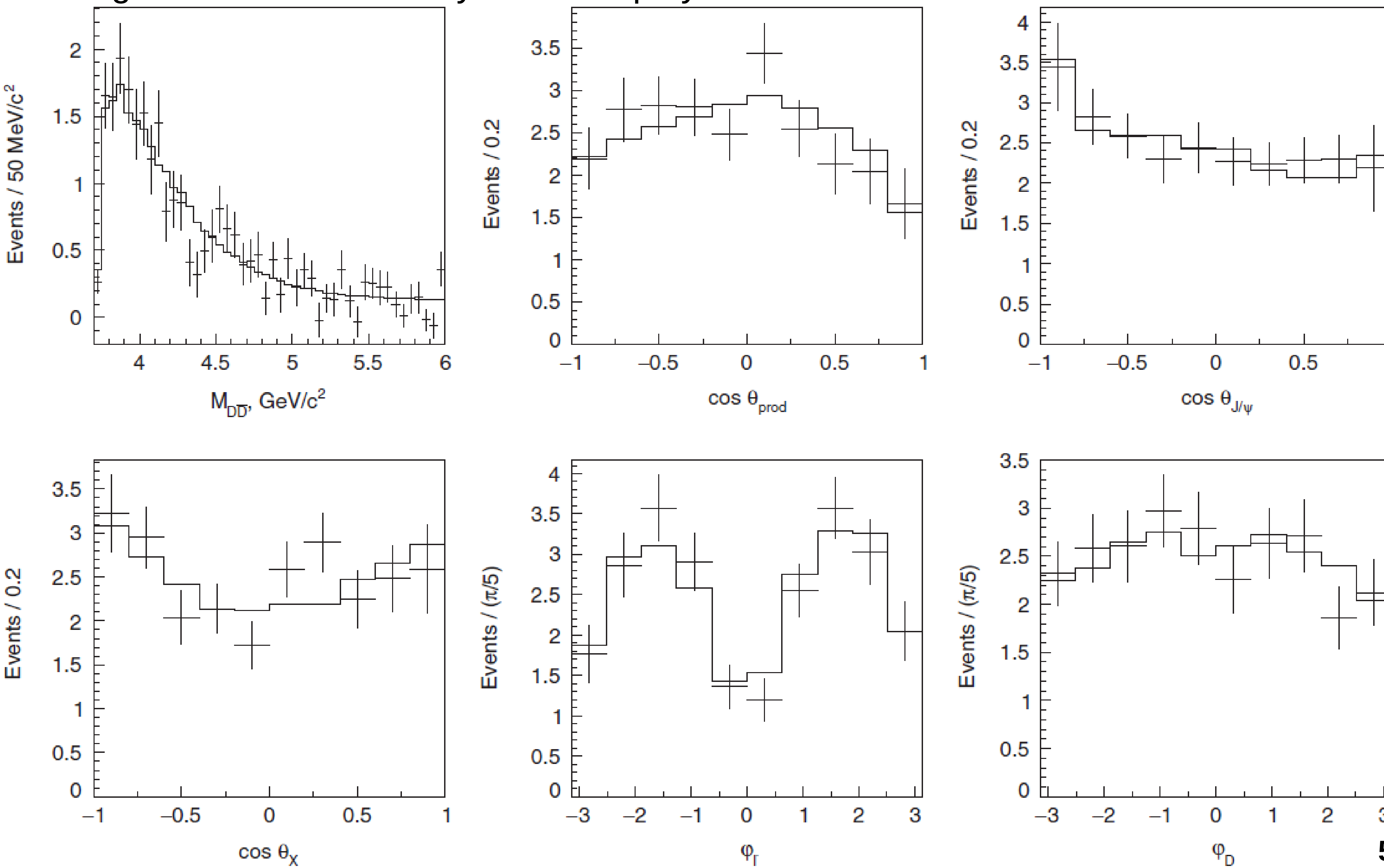
Observation of $\chi_{c0}(2P)$ in $e^+e^- \to J/\psi D\bar{D}$

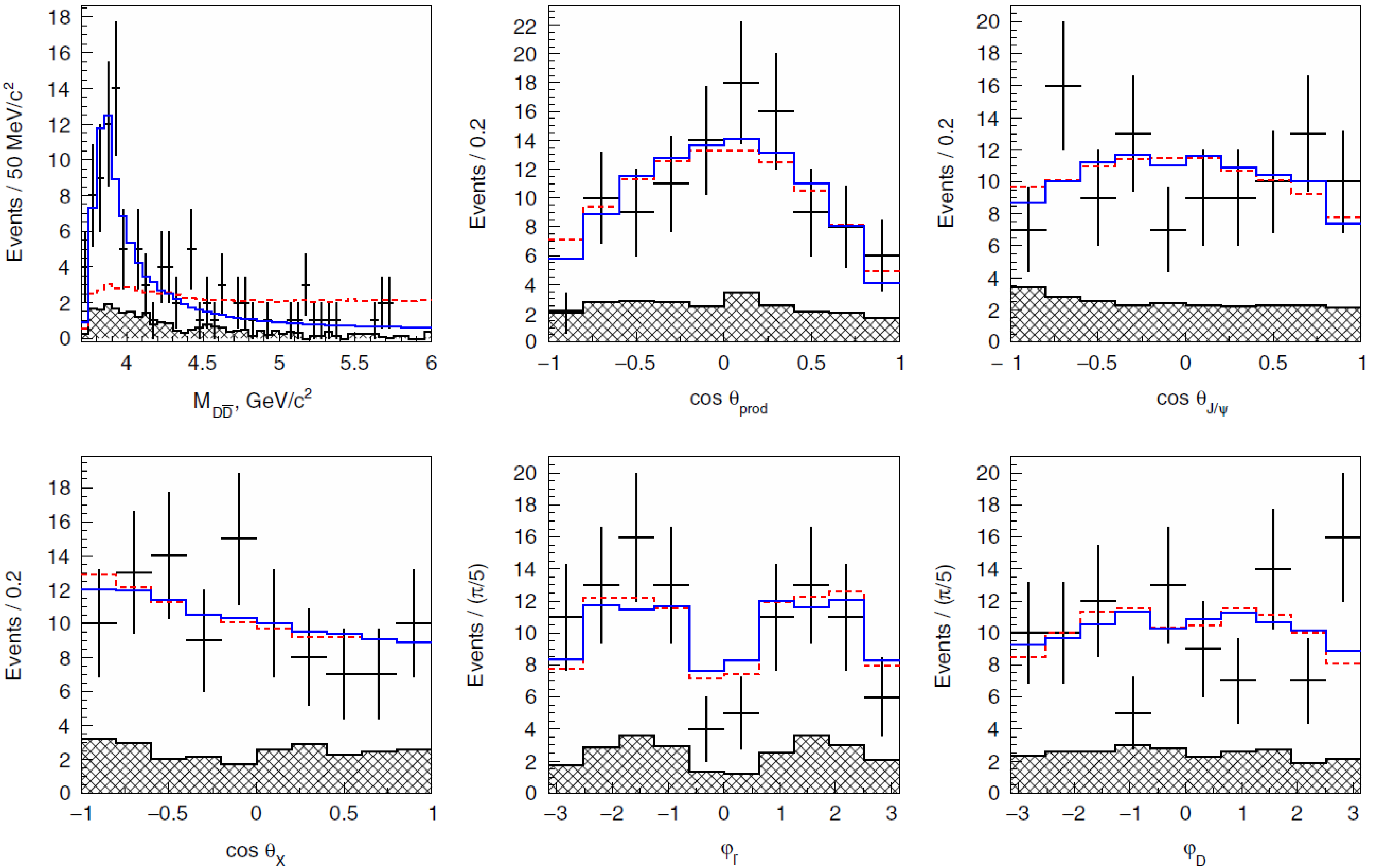
Amplitude analysis: 6 dimensions, $M_{D\bar{D}}$, θ_{prod}, $\theta_{J/\psi}$, θ_{X*}, ϕ_{l-}, ϕ_D.

Background is described by 2nd order polynomia.



Observation of $\chi_{c0}(2P)$ in $e^+e^- \to J/\psi D\bar{D}$

Fit to the data: Signal, non-resonant only, background



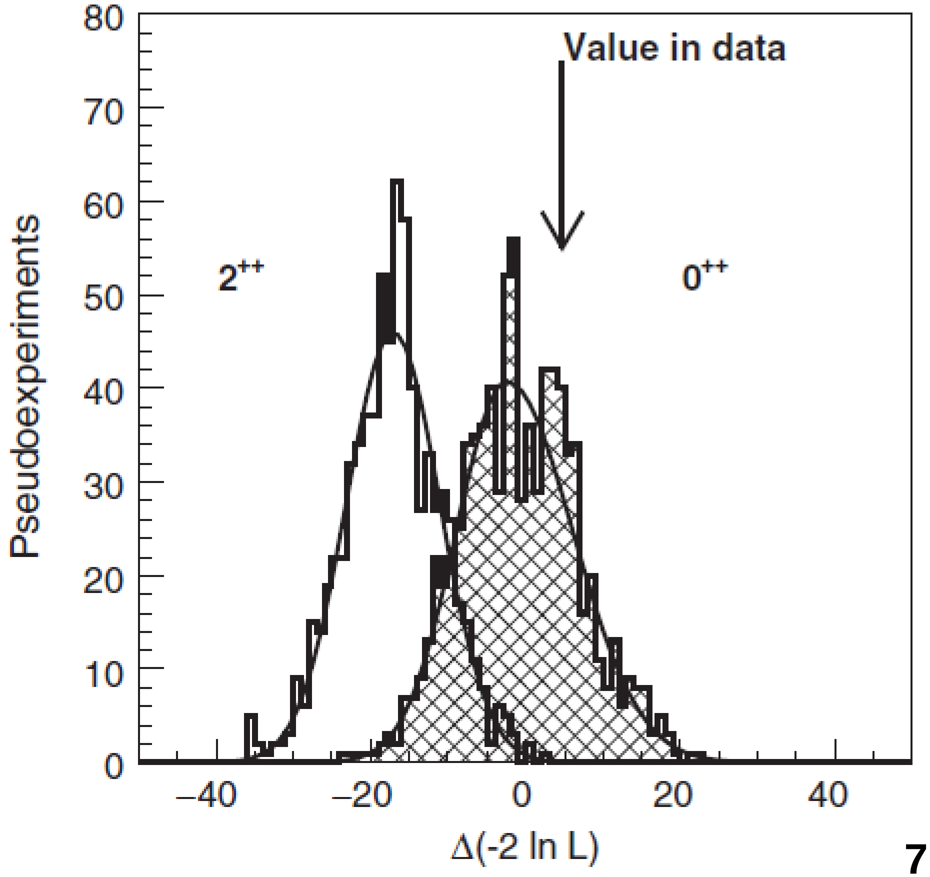
Observation of $\chi_{c0}(2P)$ in $e^+e^- \to J/\psi D\bar{D}$

- A new charmonium-like state, the X*(3860) is observed, with mass of $3862^{+26}_{-32}{}^{+40}_{-13}$ MeV/c^2, and width $201^{+154}_{-67}{}^{+88}_{-82}$ MeV.

- The J^{PC} 0^{++} is preferable, from 2^{++} at the level of 2.5σ.

- X*(3860) consistent with $\chi_c^0(2P)$ charmonium state hypotheses.

- The measured mass is close to potential model expectations for the $\chi_{c0}(2P)$.



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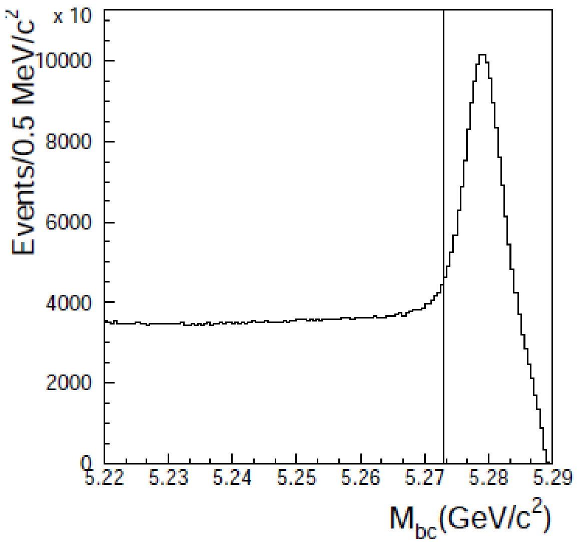
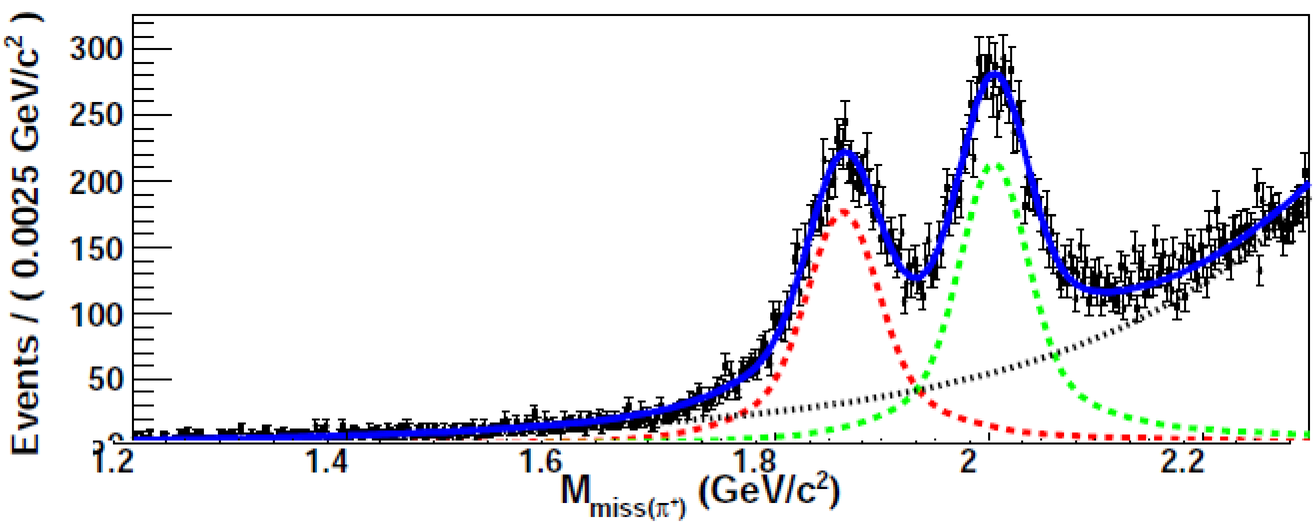
$B^+ \to X_{cc} K^+$

X(3872) observed by Belle. $J^{PC}=1^{++}$ is confirmed by LHCb. Most natural explanation S-wave $D^0\bar{D}^{*0}$ molecular state. High cross section production in $p\bar{p}$ by CDF suggests admixture of molecular and $\chi_{c1}(2P)$. Absolute branching measurement of $B^+ \to X(3872)K^+$ would help to measure $X(3872) \to F$ branching fractions and understand its nature.





Inclusive reconstruction of other B^- and K^+ from signal B^+. Fit to the K^+ recoil mass distribution. Cross check channel: $B^+ \to \bar{D}^{(*)0} \pi^+$.

Mode	$N_{\rm sig}$	$(\mu_{\rm data} - \mu_{\rm MC})$ (MeV/c^2)	$(\sigma_{\rm data}/\sigma_{\rm MC})$	$\epsilon(10^{-3})$	$\mathcal{B}$ (10^{-3})	World average for $\mathcal{B}$ (10^{-3}) [10]
$B^+ \to \pi^+ \bar{D}^0$	8550 ± 190	-0.5 ± 0.8	0.994 ± 0.025	2.48 ± 0.02	$4.34 \pm 0.10 \pm 0.25$	4.80 ± 0.15
$B^+ \to \pi^+ \bar{D}^{*0}$	9980 ± 250	-0.8 ± 0.8	1.035 ± 0.029	2.61 ± 0.02	$4.82 \pm 0.12 \pm 0.35$	5.18 ± 0.26

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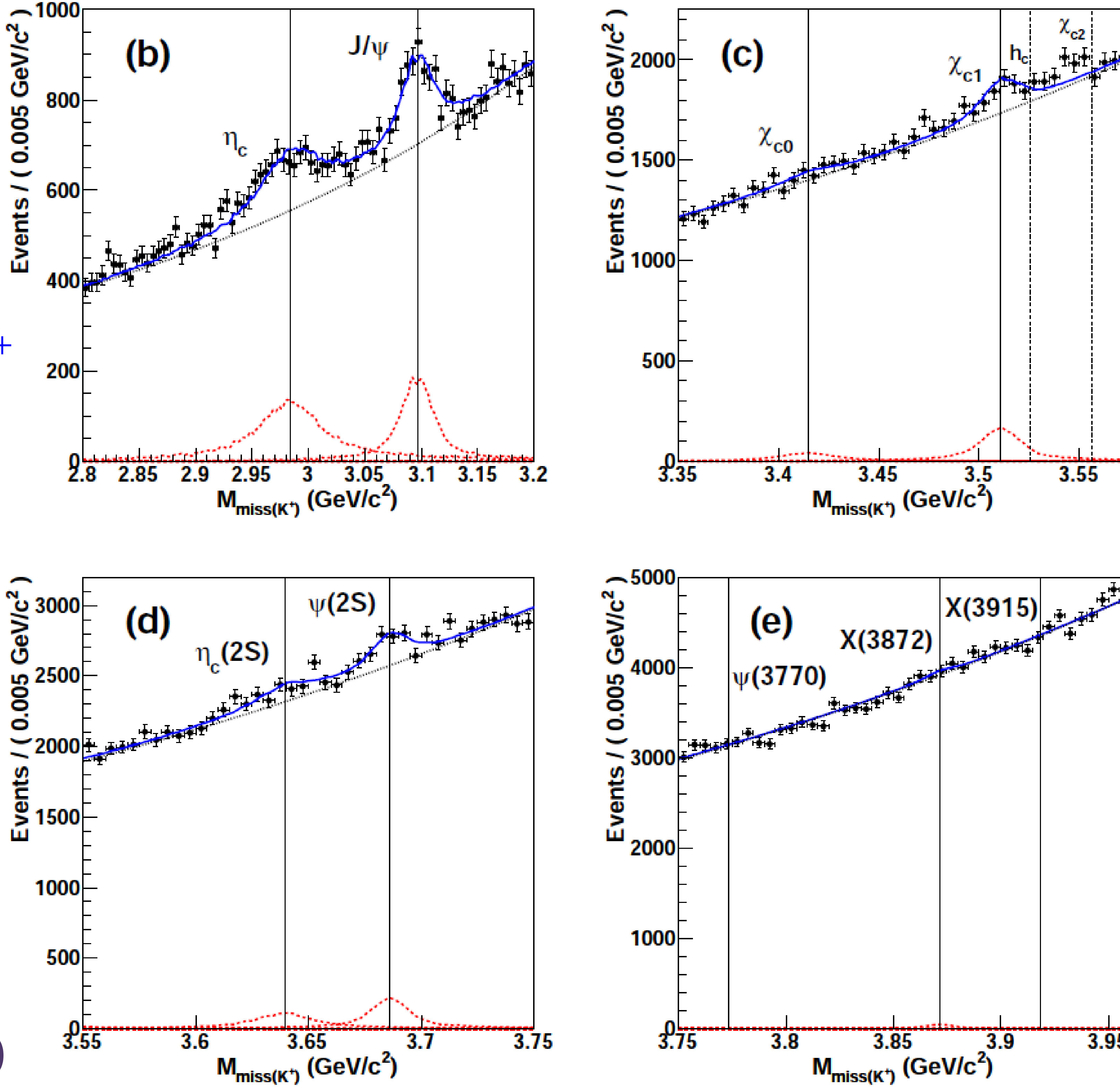
$B^+ \rightarrow X_{cc} K^+$



Phys.Rev.D97 012005 (2018)

$B^+ \to X_{cc} K^+$

- $B^+ \to X_{cc} K^+$ branching fractions have been measured.
- We significantly improve knowledge for η_c and $\eta_c(2S)$ branchings.
- Results for J/ψ, χ_{c0}, χ_{c1} and $\psi(2S)$ are consistent with world average.
- No significant signals are observed for $\psi(3770)$, X(3872), X(3915). We set 90% CL ULs.

Mode	Yield	Significance (σ)	$\epsilon(10^{-3})$	$\mathcal{B}$ (10^{-4})	World average for $\mathcal{B}$ (10^{-4}) [10]
η_c	2590 ± 180	14.2	2.73 ± 0.02	$12.0 \pm 0.8 \pm 0.7$	9.6 ± 1.1
J/ψ	1860 ± 140	13.7	2.65 ± 0.02	$8.9 \pm 0.6 \pm 0.5$	10.26 ± 0.031
χ_{c0}	430 ± 190	2.2	2.67 ± 0.02	$2.0 \pm 0.9 \pm 0.1$ (< 3.3)	$1.50^{+0.15}_{-0.14}$
χ_{c1}	1230 ± 180	6.8	2.68 ± 0.02	$5.8 \pm 0.9 \pm 0.5$	4.79 ± 0.23
$\eta_c(2S)$	1050 ± 240	4.1	2.77 ± 0.02	$4.8 \pm 1.1 \pm 0.3$	3.4 ± 1.8
$\psi(2S)$	1410 ± 210	6.6	2.79 ± 0.02	$6.4 \pm 1.0 \pm 0.4$	6.26 ± 0.24
$\psi(3770)$	-40 ± 310	-	2.76 ± 0.02	$-0.2 \pm 1.4 \pm 0.0$ (< 2.3)	4.9 ± 1.3
$X(3872)$	260 ± 230	1.1	2.79 ± 0.01	$1.2 \pm 1.1 \pm 0.1$ (< 2.6)	(< 3.2)
$X(3915)$	80 ± 350	0.3	2.79 ± 0.01	$0.4 \pm 1.6 \pm 0.0$ (< 2.8)	-

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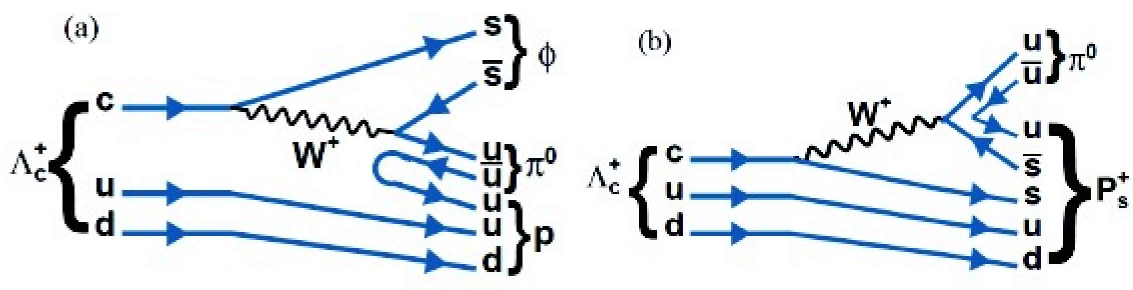
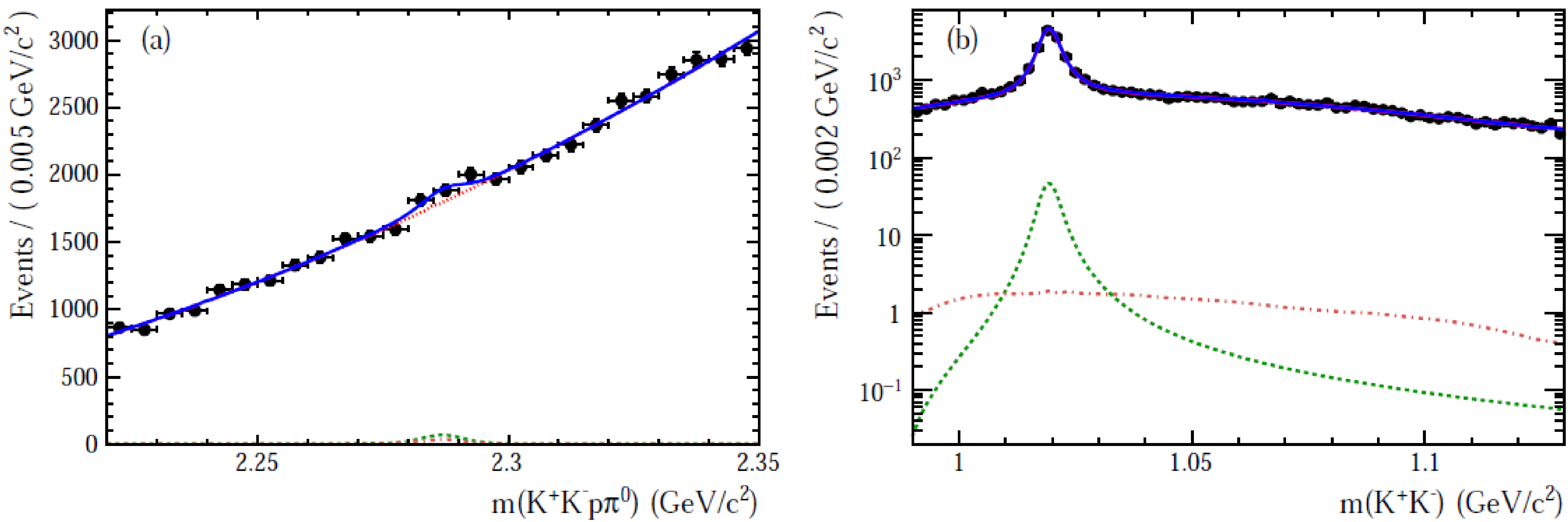
Search for pentaquark in $\Lambda_c \to P_s^+[\varphi p]\pi^0$

Observation of two hidden-charm pentaquark states, $P_c^+(4380)$ and $P_c^+(4450)$, by LHCb motivate us to search for hidden-strange partner $P_s^+ \to \varphi(1019)\,p$.

We use decay $\Lambda_c \to \varphi\, p\, \pi^0 \to K^+ K^- p\, \pi^0$.





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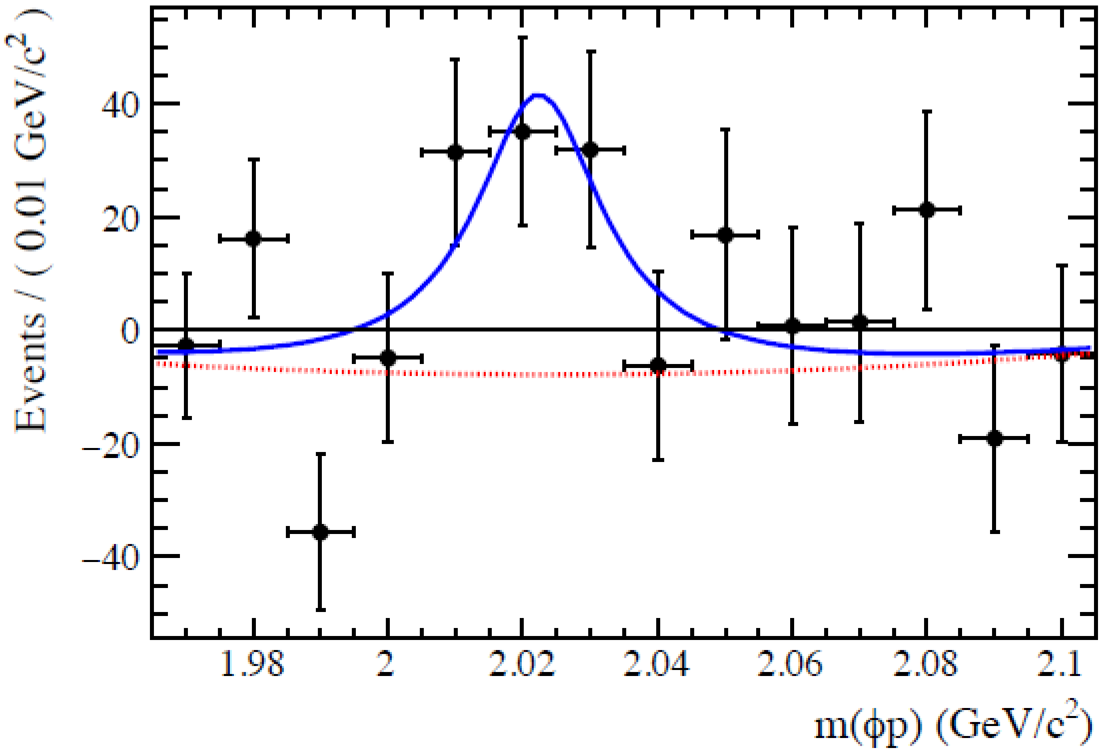
Search for pentaquark in $\Lambda_c \to P_s^+[\varphi p]\pi^0$

Significance of $\Lambda_c \to \varphi p \pi^0$ signal is below 3σ. Therefore we set 90% CL UL.

$$\frac{\mathcal{B}(\Lambda_c^+ \to \phi p \pi^0)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (1.538 \pm 0.641^{+0.077}_{-0.100}) \times 10^{-3}$$

$$\mathcal{B}(\Lambda_c^+ \to \phi p \pi^0) < 15.3 \times 10^{-5},$$
$$\mathcal{B}(\Lambda_c^+ \to K^+K^- p \pi^0)_{\mathrm{NR}} < 6.3 \times 10^{-5},$$



Fit gives 78 ± 28 events for $\Lambda_c \to P_s^+[\varphi p]\pi^0$. Local significance is below 3σ. 90% CL UL is set.

$B(\Lambda_c \to P_s^+ \pi^0)\, B(P_s^+ \to \varphi p) < 8.3\ 10^{-5}$

Phys.Rev.D96 051102 (2017)

Summary

- Observation of charmonium-like state $X^*(3860)$, consistent with $\chi_{c0}(2P)$.

  X(3915) observed by the Belle is NOT $\chi_{c0}(2P)$.

- The branching fractions of $B^+ \to X_{cc} K^+$ decays have been measured.

  Statistics is not enough to measure branching fraction of $B^+ \to X(3872) K^+$.

- No hidden-strangeness pentaquark $P_s^+ \to \varphi p$ is found in decay $\Lambda_c \to \varphi p \pi^0$.

- More exciting results are going to come from Belle II.

  Stay tuned!