



Recent results from Belle for pentaquark states search

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第四届强子与重味物理理论与实验联合研讨会,兰州

2025.03.22

Overview

- ➢ Belle and Belle II detector.
- Charmed pentaquark candidates reported by LHCb.
- Study on P[±]_c → p(\bar{p}) J/ψ in Υ(1S, 2S)
 inclusive decay.
- Study on P⁰_{ccs} → Λ(Λ) J/ψ in Y(1S, 2S)
 inclusive decay.
- ➤ Summary



KEKB and Belle Detector





SuperKEKB and Belle II Detector





Candidates of pentaguark states







Sci.Bull. 66 1278 (2021) $\Xi_b^- \to K^- + \Lambda J/\psi$







Where to search for these potential pentaquark states at Belle/Belle II?

OR

A clue: production of hyperons and deutrons is enhanced in $\Upsilon(1S, 2S)$ inclusive decays.



Study on $P_c^{\pm} \rightarrow p(\overline{p}) J / \psi$ in $\Upsilon(1S, 2S)$ inclusive decay (arXiv:2403.04340)

Event selection





We search for P_c states in pJ/ψ final states in $\Upsilon(1S, 2S)$ inclusive decay.

 $J/\psi \rightarrow l^+ l^-, l = e \text{ or } \mu$

Basic event Selection

- 3 well measured charged tracks.
- Identification of e^{\pm} , μ^{\pm} , and p^{\pm} .
- Λ veto for p candidates.
- Impact parameters between p and leptons ($\Delta dz < 0.5$ cm).
- \succ Cut on $M_{recoil}^2(pJ/\psi)$
 - $M_{recoil}^2(pJ/\psi) > 10 \, (GeV/c^2)^2$

Invariant mass distributions



E

Fit to $M(pJ/\psi)$



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40000 The formula used in the fit to events $no - P_c MC$ Signal MC from J/ψ mass region is: 1600 ± 1400 $f_{PDF} = f_R + f_{no-P_c} + f_{bkg}$ $no - P_c$ MC is used to simulate 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5 M(p(ρ)J/ψ) GeV/c² 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5 M(p(φ)J/ψ) GeV/c² 5 4.1 4.1 the non-resonance process. - Data - Data Data Signal MC Signal MC Entries/25 MeV/c² Entries/25 MeV/c² Signal MC 20 20 Entries/25 MeV/c² 20 No-Pc MC No-Pc MC No-Pc MC •••• bkg from sideband •••• bkg from sideband bkg from sideband 15⊦ 15 10 10 10 4.2 4.2 4.2 4.4 4.6 4.8 4.4 4.6 4.8 5 4.4 4.6 5 5 $M[p(\overline{p})J/\psi]$ (GeV/c²) $M[p(\overline{p})J/\psi]$ (GeV/c²) $M[p(\overline{p})J/\psi]$ (GeV/c²) $P_{c}(4457)^{+}$ $P_{c}(4312)^{+}$ $P_{c}(4440)^{+}$

Fit to $M(pJ/\psi)$





	$\Upsilon(1S)$ decays			$\Upsilon(2S)$ decays		
	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$
$N_{ m fit}^{ m A}$	6 ± 8	10 ± 11	13 ± 10	23 ± 9	30 ± 13	2 ± 15
$N_{ m fit}^{ m A,UL}$	20	27	30	40	54	13
$N_{ m fit}^{ m B}$	8 ± 9	10 ± 11	10 ± 9	24 ± 9	29 ± 11	3 ± 12
$N_{ m fit}^{ m B,UL}$	24	28	31	42	53	15
$N_{ m sig}^{ m UL}$	27	43	38	50	77	28
$\mathcal{B}^{\mathrm{UL}}$ (×10 ⁻⁶)	3.9	6.2	5.5	4.7	7.2	2.6

- ➤ No significant P_c state is obtained in the pJ/ψ of $\Upsilon(1S, 2S)$ inclusive decays.
- We set upper limits on P_c productions from $\Upsilon(1S, 2S)$ inclusive decay.
- ➢ We measure the branching fractions of pJ/ψ productions from Y(1S, 2S)
 inclusive decay:
 - $Br[\Upsilon(1S) \to pJ/\psi + anything] =$ (4.27 ± 0.16 ± 0.20) × 10⁻⁵
 - $Br[\Upsilon(2S) \to pJ/\psi + anything] =$ (3.59 ± 0.14 ± 0.16) × 10⁻⁵



Study on $P_{c\bar{c}s}^0 \rightarrow J/\psi \Lambda/\bar{\Lambda}$ in $\Upsilon(1S, 2S)$ inclusive decay (arXiv:2502.09951)

Event selection



We search for $P_{c\bar{c}s}^0$ states in $\Lambda J/\psi$ final states in $\Upsilon(1S, 2S)$ inclusive decay.

$$J/\psi \rightarrow l^+ l^-, l = e \text{ or } \mu$$

 $\Lambda \rightarrow p\pi^-$

Basic event Selection

- 4 well measured charged tracks.
- Identification of e^{\pm} , μ^{\pm} .

Λ selection

- Select Λ with neural network framework (nisKsFinder).
- We can get about 96% selection
 efficiency for Λ with nisKsFinder.



(a)(b)~ $\Upsilon(1S)$, (c)(d)~ $\Upsilon(1S)$, (e)(f)~continuum process

Event selection





> 89 fb-1 data sample collected at 10.52 GeV is used to estimate the continuum production.
 > J/ψ mass window:
 |M_{l+l}- - 3.0969| < 3 * 10.0 MeV/c²
 > Λ mass window:
 |M_{pπ}- - 1.1156| < 3 * 1.4 MeV/c²

(a)(d)~ $\Upsilon(1S)$, (b)(e)~ $\Upsilon(1S)$, (c)(f)~continuum process.

Both Λ and J/ψ are clear.

$\Lambda J/\psi$ production





The data shows the first observation of $\Upsilon(1S)$, $\Upsilon(2S)$ decays into $\Lambda J/\psi$ final states and makes measurements of their branching fractions:

 $B[\Upsilon(1S) \rightarrow J/\psi \Lambda/\overline{\Lambda} + anything] = (36.9 \pm 5.3 \pm 2.4) \times 10^{-6}$ $B[\Upsilon(2S) \rightarrow J/\psi \Lambda/\overline{\Lambda} + anything] = (22.3 \pm 5.7 \pm 3.1) \times 10^{-6}$

Invariant mass distributions of $\Lambda J/\psi$





- ➤ We use $M_{\Lambda J/\psi} = M_{l^+l^-p\pi^-} M_{l^+l^-} M_{p\pi^-} + m_{\Lambda} + m_{J/\psi}$ to improve the mass resolution σ_M (11.6 MeV/c² → 2.8 MeV/c²)
- Excess seen near 4.46 GeV in both $\Upsilon(1S)$ and $\Upsilon(2S)$ data.

Fit to $M(\Lambda J/\psi)$





> Fit strategy

• The data was fitted by a binned max likelihood fit, with

 $f_{PDF} = f_R + f_{no-P_{c\bar{c}s}} + f_{Sideband}$

 We include a Gaussian constraint using prior knowledge of the LHCb, and measurement and minimize the value of:

$$-2lnL' \equiv \frac{(m-m_{LHCb})^2}{\sigma_{m_{LHCb}}^2} + \frac{(m-\Gamma_{LHCb})^2}{\sigma_{\Gamma_{LHCb}}^2}$$

- Signal yield
 - $N_{P_{c\overline{cs}}(4459)} = 21 \pm 5$
 - $\Delta(-2lnL) = 14.58 (\text{local } 3.8\sigma)$
 - Significance is determined to be 3.3σ

Fit to $M(\Lambda J/\psi)$





> Resonance parameters

- The Resonance parameters are determined by the fit without any constrain.
 - $M = 4471.7 \pm 4.8 \pm 0.6 \text{ MeV}/c^2$
 - $\Gamma = 21.9 \pm 13.1 \pm 2.7$ MeV
- $\succ P_{c\bar{c}s}$ production
 - $B[(\Upsilon(1S) \rightarrow P_{c\bar{c}s}(4459)^0/\bar{P}_{c\bar{c}s}(4459)^0 + \text{anything}] =$ (3.5 ± 2.0 ± 0.2) × 10⁻⁶
 - $B[(\Upsilon(2S) \rightarrow P_{c\bar{c}s}(4459)^0/\bar{P}_{c\bar{c}s}(4459)^0 + \text{anything}] =$ (2.9 ± 1.7 ± 0.4) × 10⁻⁶
 - The upper limits of $P_{c\bar{c}s}(4338)^0$ production are determined to be at 10^{-6} level





- We search for P_c states in the pJ/ψ final state from $\Upsilon(1S, 2S)$ inclusive decays and no significant P_c state is obtained.
- We search for $P_{c\bar{c}s}$ states in the $\Lambda J/\psi$ final state from $\Upsilon(1S, 2S)$ inclusive decays and a peak is found in the region of the $P_{c\bar{c}s}(4459)^0$ from $\Lambda J/\psi$ mass spectrum while no sign of $P_{c\bar{c}s}(4338)^0$.
- The significance of $P_{c\bar{c}s}(4459)^0$ is determined to be 3.3 σ including systematics.

Thank you very much!



BACK UP

Generic MC





Invariant mass from MC





Systematics from Lambda selection



- The systematic error was studied by comparing data and MC. We use the 771fb⁻¹ $\Upsilon(4S)$ data sample with HadronB(J) skim type which passed the $B^{\pm} \rightarrow \Lambda \bar{\Lambda} K^{\pm}$ pre-selection criteria, listing in Table below.
- The selection efficiency of Λ is 96.5 \pm 0.3% for MC and 96.6 \pm 0.6% for data.

Table: The pre-selection criteria for $B^{\pm} \rightarrow \Lambda \bar{\Lambda} K^{\pm}$.

	Selection criteria
K^\pm selection	atcPIDBelle(3,2)>0.6 and $atcPIDBelle(3,4)>0.6$
	$dr(K^{\pm}) <$ 0.5 cm and $dz(K^{\pm}) <$ 5 cm
Λ selection	ksnbNoLam<-0.4
	ksnbVLike>0.5
Λ signal region	$ M(p\pi)-1.1156 < 3*0.0014~{ m GeV}/c^2$



Systematics from Lambda selection



- To determine the systematic uncertainties, We divide the samples into 6 momentum bins.
- The signal efficiency and data efficiency are compared before and after nisKsfinder variables cuts.
- We quote the double ratio $\left(\left| \frac{\epsilon_{DT}}{\epsilon_{MC}} 1 \right| \right)$ to be the systematic uncertainties.

Λ momentum	Data Efficiency(%)	MC Efficiency(%)	Ratio
$0-1.0~{ m GeV/c}$	99.32 ± 0.04	94.06 ± 0.01	1.056
$1.0-1.5~{ m GeV/c}$	92.68 ± 0.01	95.84 ± 0.01	0.967
$1.5-2.0~{ m GeV/c}$	95.28 ± 0.01	95.35 ± 0.01	0.999
$2.0-2.5~{ m GeV/c}$	93.04 ± 0.01	95.02 ± 0.01	0.979
$2.5-3.0~{ m GeV/c}$	95.50 ± 0.02	95.98 ± 0.01	0.995
> 3.0 GeV/c	97.76 ± 0.05	95.03 ± 0.01	1.029

Total Systematics $(\Lambda J/\psi)$



Source	$\Upsilon(1S)$	$\Upsilon(2S)$	e^+e^- annihilation
PID	1.4	1.4	1.4
Tracking	1.4	1.4	1.4
Λ selection	4.0	3.6	3.4
J/ψ mass window	2.1	1.0	2.0
Λ mass window	1.6	3.2	2.7
Mean mass of $q\bar{q}$ system	1.8	1.7	1.8
Accompanying particle	2.3	3.5	1.9
Branching fractions	1.4	6.3	1.4
$N_{\Upsilon(1S,2S)}$	2.0	2.6	_
Luminosity	_	_	1.4
MC sample statistics	0.5	0.5	0.5
$1 + \delta_{\rm ISR}$	_	_	1.0
Sum in quadrature	6.4	9.5	6.2



Source	$\Upsilon(1S)$ decay	$\Upsilon(2S)$ decay	$\sigma(e^+e^- \to pJ/\psi + anything)$
Particle identification	2.1	2.1	2.1
Tracking	1.1	1.1	1.1
J/ψ signal region	0.5	0.4	0.2
$M_{\rm recoil}^2(pJ/\psi)$ requirement	0.4	1.1	2.2
$\mathcal{B}(J/\psi \to \ell^+ \ell^-)$	0.6	0.6	0.6
$1 + \delta_{\rm ISR}$			1.0
^[a] Scale factor f_{scale}	11.2	4.9	
Modeling in MC simulation	2.8	2.4	2.6
Number of $\Upsilon(1, 2S)$ events	2.2	2.3	
Integrated luminosity			1.4
Statistics of MC samples	0.5	0.5	0.5
Sum in quadrature	4.4	4.3	4.6