Evidence of a $J/\psi\Lambda$ resonance and observation of excited Ξ^- states in $\Xi_b^- \to J/\psi \Lambda K^-$ decays

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Bo Fang

Wuhan University

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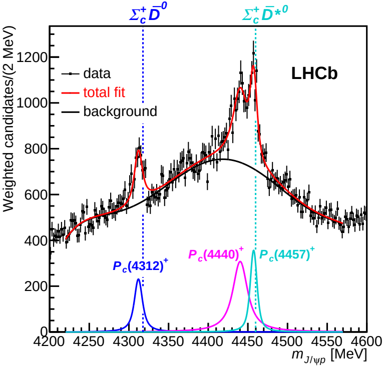
Outline

Observation of pentaquark states in $\Lambda_b^0 \to J/\psi\, pK^-$ decays

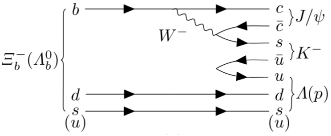
- In 2015, the LHCb collaboration reported the first observation of two pentaquark states($P_c(4380)^+$ and $P_c(4450)^+$) in the decays of $\Lambda_b^0 \to J/\psi\, pK^-$.(Phys. Rev. Lett. 115, 072001)
- In 2019, a new narrow pentaquark state($P_c(4312)^+$) and two-peak structure of the $P_c(4450)^+$ were observed with the inclusion of RunII data at LHCb.(Phys. Rev. Lett. 122, 222001)



Motivation

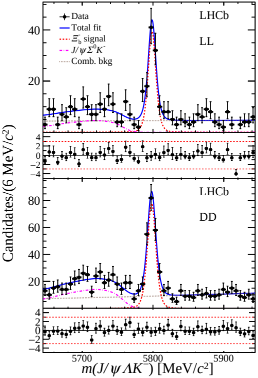
Why $\Xi_b^- \to J/\psi \Lambda K^-$?

- With u quark changed to s quark, $\Xi_b^- \to J/\psi \Lambda K^-$ is an ideal channel to search for hidden-charm pentaquark state with strangeness S = -1.



previous analysis in $\Xi_b^- \to J/\psi \Lambda K^-$:

- This decay ($\Xi_b^- \to J/\psi \Lambda K^-$) was observed and its branching ratio has been measured with RunI data in LHCb. (Phys. Lett. B772 (2017) 265)

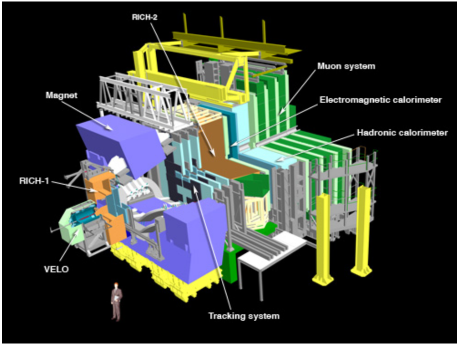


about 310 signal decays

Analysis strategy

- Reconstruction and selections:
  - Similar to the previous analysis in RunI.
  - Some selection criteria improved.
- 6-D amplitude analysis:
  - Similar to the analysis of $\Lambda_b^0 \to J/\psi\, pK^-$ in 2015.
  - Λ taken as a final-state particle.
  - Formula cross checked with the Dalitz-Plot Decomposition formula and updated.

The LHCb detector



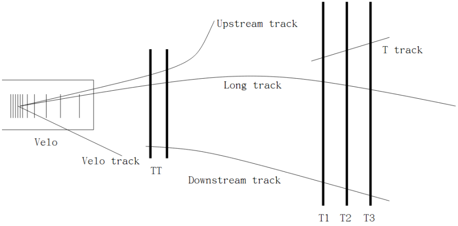
- A forward spectrometer : $2 < \eta < 5$
- Dedicated to precise study of b, c particles.
- Excellent tracking and vertexing.
- Good PID performance.

Data sample:

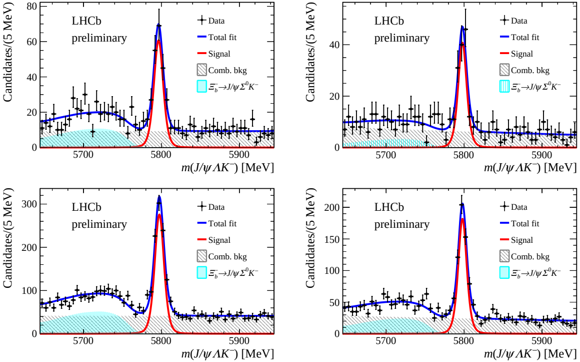
- Lumi $= 9.0$ fb^{-1}. (3.0fb^{-1} for RunI, 6.0fb^{-1} for RunII).

Selections:

- $\Xi_b^- \to J/\psi \Lambda K^-$, $J/\psi \to \mu^+\mu^-$, $\Lambda \to p\pi^-$
- Λ candidates are reconstructed into two categories:
  - two daughters with *Long track*(LL).
  - two daughters with *Downstream track*(DD).
- Selections are similar to the one used in previous analysis, except:
  - remove transverse momentum cuts and PID cuts for $p\pi^-$(low Q value).
  - loosen the $\chi^2_{\rm IP}$ of the associated K^-(included in MVA).



Mass spectrum fit for Ξ_b^- candidates



RunI DD(top left)
RunII DD(bottom left)

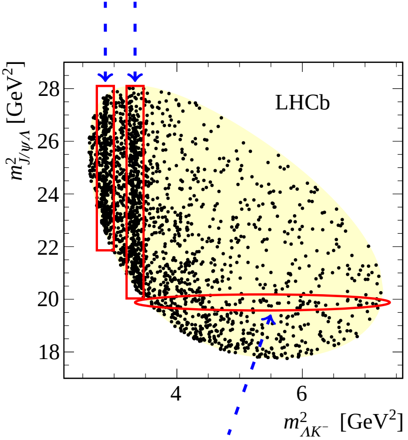
RunI LL(top right)
RunII LL(bottom right)

- sig: Hypatia function
- comb bkg: exponential function
- phys bkg: $\Xi_b^- \to J/\psi \Sigma^0 K^-$ with $\Sigma^0 \to \Lambda\gamma$ with missing γ, generator level MC convoluted with resolution Gaussian.

In total, we obtain about 1750 signal decays. Background takes 22.6% in $\pm 2\sigma$ signal region (about$\pm 15\,\mathrm{MeV}$).

Dalitz plots

- Two excited Ξ^- states



- Possible P^0_{cs} state?
  Amplitude analysis required.

- Invariant mass squared of ΛK^- versus $J/\psi\,\Lambda$ for candidates within $\pm 2\sigma$ of the Ξ_b^- mass.
- The yellow area shows the kinematically allowed region.
- Ξ_b^-, J/ψ and Λ are constrained to PDG mass, Ξ_b^- constrained to point back to primary vertex.

Amplitude Analysis Strategy

- Amplitude analysis in $\Xi_b^- \to J/\psi \Lambda K^-$ is performed similar to Pentaquark analysis of $\Lambda_b^0 \to J/\psi p K^-$ in 2015 . Here we take Λ as a final state particle, since Λ has J^P the same as proton, so the code for $\Lambda_b^0 \to J/\psi p K^-$ is directly used.
- Formula cross checked with the Dalitz-Plot Decomposition formula and updated.

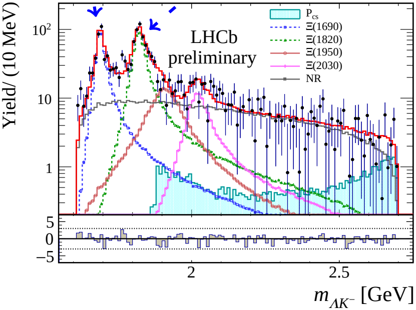
- Ξ^* resonances listed in PDG with a rank higher than 2 star are considered.
- Ξ^* spectroscopy is not well measured, J^P of many states are not determined.
- Here we examine different J^P combinations.

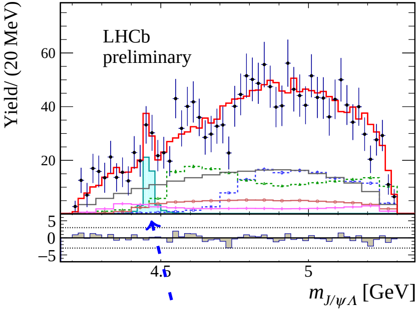
State	J^P	M(MeV)	Γ(MeV)	Couplings used(max)	J^P examined
$\Xi(1690)^-$	$?^?$	1690 ± 10	<30	4(4)	$(1/2, 3/2)^\pm$
$\Xi(1820)^-$	$3/2^-$	1823 ± 5	24^{+15}_{-10}	3(6)	$3/2^-$
$\Xi(1950)^-$	$?^?$	1950 ± 15	60 ± 20	3(6)	$(1/2, 3/2, 5/2)^\pm$
$\Xi(2030)^-$	$5/2^?$	2025 ± 5	20^{+15}_{-5}	3(6)	$5/2^\pm$
NR	$1/2^-$	-	-	4(4)	$1/2^-$
P^0_{cs}	$?^?$	?	?	1(4)	$(1/2, 3/2, 5/2)^\pm$

- PDG errors of masses and widths are used as Gaussian constraints for $\Xi(1950)^-$ and $\Xi(2030)^-$. We measure masses, widths and fit fractions of $\Xi(1690)^-$ and $\Xi(1820)^-$, which are totally float.

Results of amplitude analysis

- Clear peaks for two Ξ^- states: $\Xi(1690)^-$, $\Xi(1820)^-$.

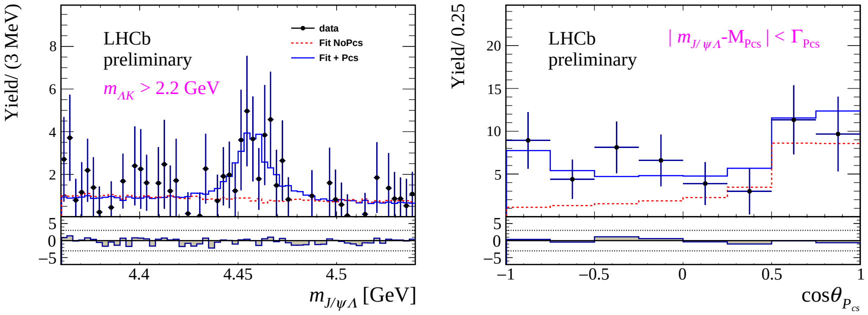




- Adding a P^0_{cs} state improves $-2ln\mathcal{L}$ by 43, corresponding to a significance of 4.3σ(stat. only).

Results of amplitude analysis

Projection of m($J/\psi\Lambda$) and cos$\theta_{P_{cs}}$ zoomed in P^0_{cs} region:



- Statistics are not enough to determine J^P of P^0_{cs} and $\Xi(1690)^-$.

Systematic uncertainties

Systematic uncertainties are evaluated for the fit fractions, masses and widths of $P_{cs}(4459)^0, \Xi(1690)^-$ and $\Xi(1820)^-$, as well as the significance of P^0_{cs}, the largest variation is taken as final systematic uncertainty:

- Change to other possible J^P of the states used.
- The modeling uncertainty includes:
  - varying hadron-size parameter in the Blatt-Weisskopf barrier factor.
  - changing the orbital angular momenta L in Ξ_b^- decay.
  - using full numbers of couplings for Ξ^- or P^0_{cs} resonances.
  - polarization of Ξ_b^-.
  - Extended model: two more Ξ^- state fixed at $2.25\,\mathrm{GeV}$ $(3/2^-)$ and $2.5\,\mathrm{GeV}$ $(1/2^-)$, removing constraints for $\Xi(1950)^-$, $\Xi(2030)^-$, and using full couplings for all Ξ^-.
  - Alternative NR ΛK^- models: constant NR + $\Xi(1620)^-$, Exp, $1/(m^2_{\Lambda K} + m^2_0)$.
- Including $\Lambda \to p\pi$ decay in the amplitude fit.
- The uncertainty due to efficiency.
- sWeights: physical background in low sideband of m$(J/\psi \Lambda K)$, correlations between fit variables and sw.

Measured results and significance

LHCb preliminary			
State	M_0 (MeV/c^2)	Γ (MeV/c^2)	Fit fraction (%)
$P_{cs}(4459)^0$	$4458.8 \pm 2.9^{+4.7}_{-1.1}$	$17.3 \pm 6.5^{+8.0}_{-5.7}$	$2.7^{+1.9+0.7}_{-0.6-1.3}$
$\Xi(1690)^-$	$1692.0 \pm 1.3^{+1.2}_{-0.4}$	$25.9 \pm 9.5^{+14.0}_{-13.5}$	$22.1^{+6.2+6.7}_{-2.6-8.9}$
$\Xi(1820)^-$	$1822.7 \pm 1.5^{+1.0}_{-0.6}$	$36.0 \pm 4.4^{+7.8}_{-8.2}$	$32.9^{+3.2+6.9}_{-6.2-4.1}$

- Final significance of the $P_{cs}(4459)^0$ state is estimated by pseudo experiments.
- After syst. uncertainty considered, the significance of the $P_{cs}(4459)^0$ state is finally determined to be 3.1σ(LHCb preliminary).

Conclusion:

- With RunI and RunII data(Lumi=9fb^{-1}), about 1750 $\Xi_b^- \to J/\psi \Lambda K^-$ decays are observed.
- A full amplitude analysis is performed, and we get these results:
    - An evidence of a new pentaquark candidate $P_{cs}(4459)^0$ in $J/\psi\Lambda$ system:
        - Including syst. uncertainty, significance is 3.1σ. (LHCb preliminary)
        - $M_0(P_{cs}) = 4458.8 \pm 2.9^{+4.7}_{-1.1}\,\mathrm{MeV}$ (LHCb preliminary)
        - $\Gamma(P_{cs}) = 17.3 \pm 6.5^{+8.0}_{-5.7}\,\mathrm{MeV}$ (LHCb preliminary)
        - fit fraction is $(2.7^{+1.9}_{-0.6}{}^{+0.7}_{-1.3})\%$ (LHCb preliminary)
    - This state is only $19\,\mathrm{MeV}$ below $\Xi_c^0 \bar{D}^{*0}$ mass threshold.

Conclusion:

- Some other results from amplitude analysis:
  - Two narrow excited Ξ^- states, $\Xi(1690)^-$ and $\Xi(1820)^-$, are observed:
    - $M_0(\Xi^-_{1690}) = 1692.0 \pm 1.3^{+1.2}_{-0.4}\,\mathrm{MeV}, \Gamma(\Xi^-_{1690}) = 25.9 \pm 9.5^{+14.0}_{-13.5}\,\mathrm{MeV}$ (LHCb preliminary)
    - $M_0(\Xi^-_{1820}) = 1822.7 \pm 1.5^{+1.0}_{-0.6}\,\mathrm{MeV}, \Gamma(\Xi^-_{1820}) = 36.0 \pm 4.4^{+7.8}_{-8.2}\,\mathrm{MeV}$ (LHCb preliminary)
    - Fit fractions are $(22.1^{+6.2}_{-2.6}{}^{+6.7}_{-8.9})\%, (32.9^{+3.2}_{-6.2}{}^{+6.9}_{-4.1})\%$ for $\Xi(1690)^-$ and $\Xi(1820)^-$, respectively. (LHCb preliminary)
  - Masses and widths of $\Xi(1690)^-$ and $\Xi(1820)^-$ are consistent with PDG value, with improved precision.
- Due to limited statistics, J^P of $P_{cs}(4459)^0$ and $\Xi(1690)^-$ states are not determined.

Thank you for your attention!