Istituto Nazionale di Fisica Nucleare

Evidence of a new pentaquark candidate in $\Xi_b^- \to J/\psi \Lambda K^-$ decay

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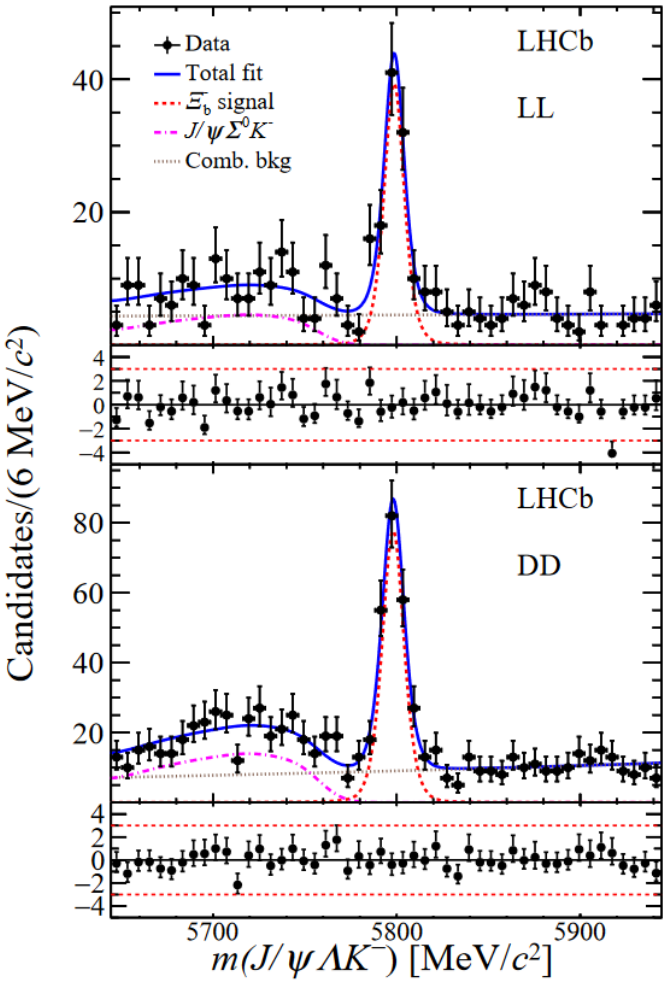
Mengzhen Wang

Outline

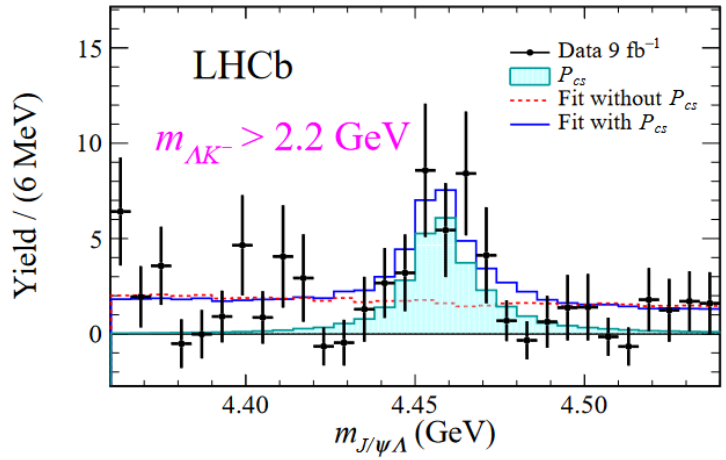
PLB 772 (2017) 265-273

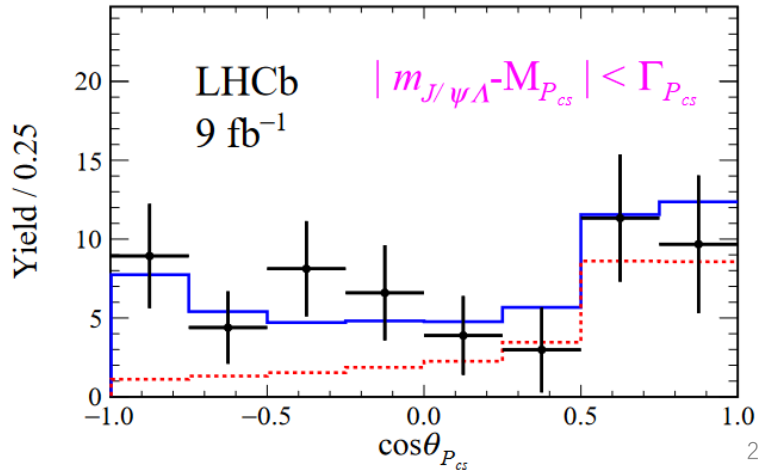
Run1: Observation of $\Xi_b^- \to J/\psi\Lambda K^-$



Science Bulletin 66 (2021) 1278

Run1+2: Am. An. & evidence of a $J/\psi\Lambda$ structure





PLB 772 (2017) 265-273

First observation of the decay $\Xi_b^- \to J/\psi \Lambda K^-$ (LHCb Run1)

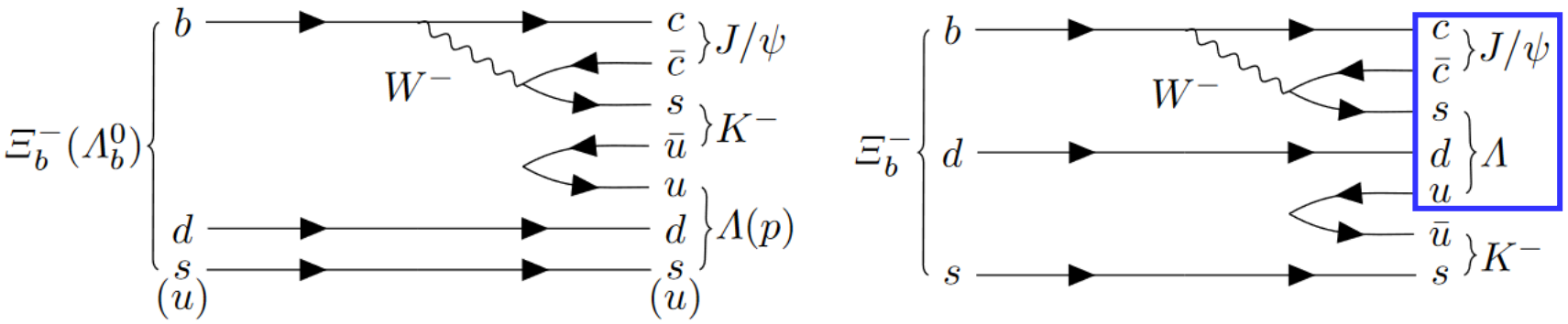
Motivation

PRL 115(2015)072001

- Pentaquark-like states observed in $\Lambda_b^0 \to J/\psi p K^-$ in 2015
- Search for the SU(3) partners

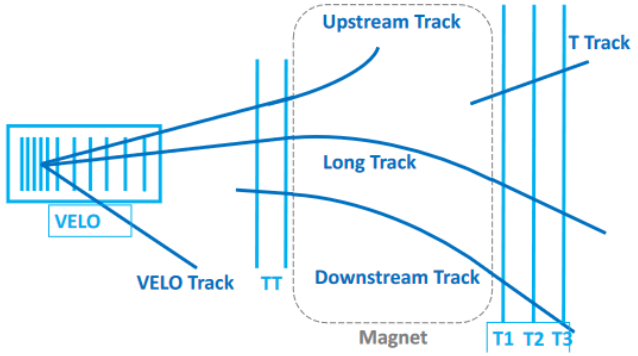
$$\Xi_b^- \to J/\psi \Lambda K^-$$

P_{cs}: $c\bar{c}uds$



- First target:
  - Search for $\Xi_b^- \to J/\psi \Lambda K^-$ using LHCb Run1 data
  - Evaluate the available signal yield for further amplitude analysis

Analysis strategy



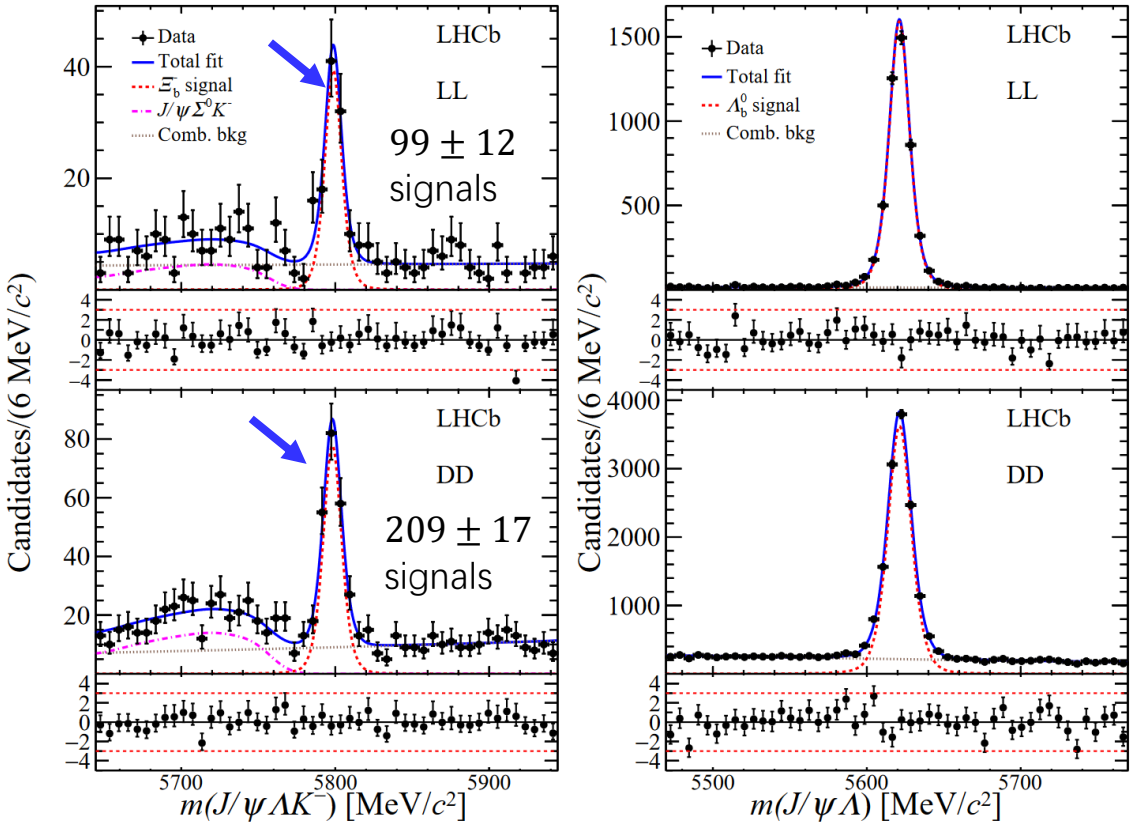
- LHCb Run1 pp data, $L{\sim}3\ \mathrm{fb}^{-1}$
- $\Lambda \to p\pi$ (Long+Long OR Down+Down); $J/\psi \to \mu^+\mu^-$
- Online selection:
  - Two high-$\mathrm{p_T}$ muons, vertexing far away from the PV
- Offline selection:
  - Use the fully reconstructed topology, kinematic & PID
  - Loose preselection + tighter MVA-based selection
  - Optimized separately for LL & DD samples
- $\Xi_b^- \to J/\psi\Lambda K^-$ signals act as peak in $m(J/\psi\Lambda K^-)$ spectrum
  - 1D mass fit for signal yield extraction
- If observed, measure the branching fraction

Measure the production ratio:

$$R_{\Xi_b^-/\Lambda_b^0} \equiv \frac{f_{\Xi_b^-}}{f_{\Lambda_b^0}} \frac{\mathcal{B}(\Xi_b^- \to J/\psi\,\Lambda K^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi\,\Lambda)} = \frac{N(\Xi_b^- \to J/\psi\,\Lambda K^-)}{N(\Lambda_b^0 \to J/\psi\,\Lambda)}\,\epsilon_{\mathrm{rel}},$$

Results

- Significant Ξ_b^- peak in $m(J/\psi\Lambda K^-)$ spectrum. Indicate 1st observation
- ~300 signals collected. Not enough for a amplitude analysis. Stay tuned with Run2 data.



Result of production ratio: $R_{\Xi_b^-/\Lambda_b^0} = (4.19 \pm 0.29\,(\text{stat}) \pm 0.15\,(\text{syst})) \times 10^{-2}$

Also a mass measurement: $M(\Xi_b^-) - M(\Lambda_b^0) = 177.08 \pm 0.47\,(\text{stat}) \pm 0.16\,(\text{syst})\ \text{MeV}/c^2.$

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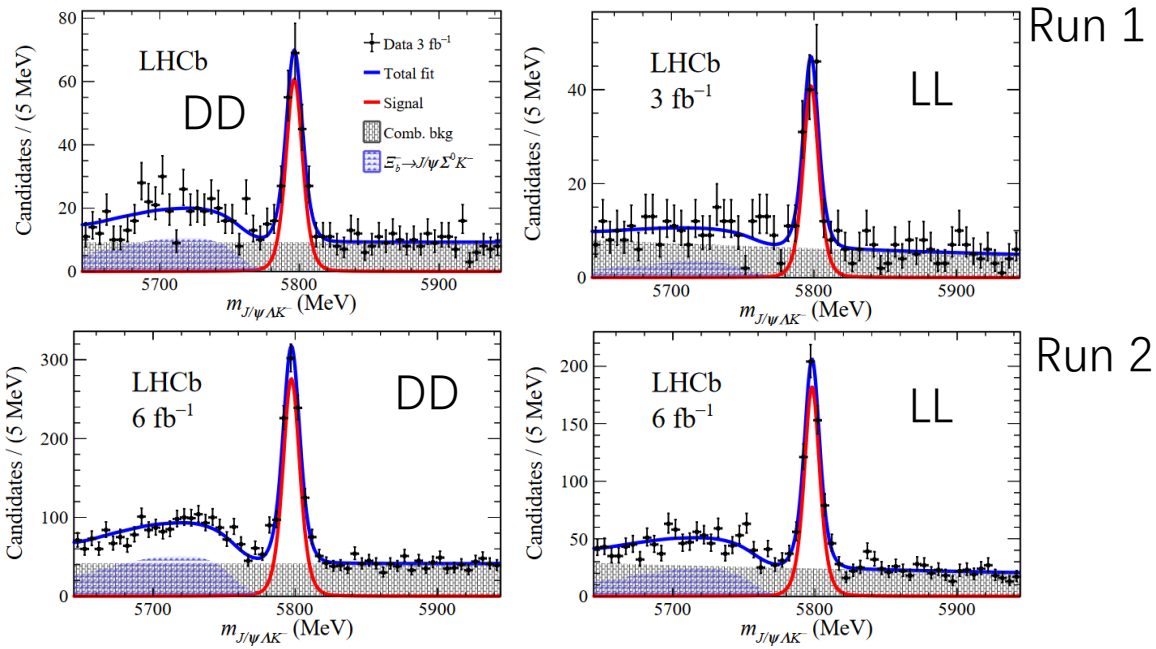
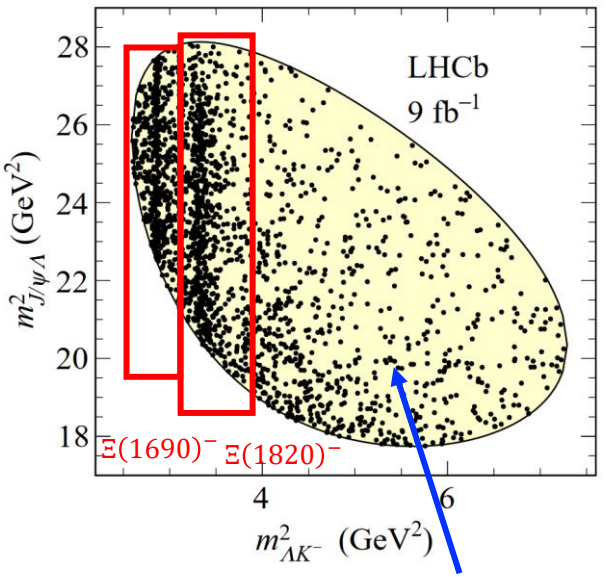
Amplitude analysis of $\Xi_b^- \to J/\psi \Lambda K^-$ decay (LHCb Run1+2)

Data sample

- Run 1+2 data: ~1750 signals, purity ~80%





Potential P_{cs} contribution?
Amplitude analysis required.
(next slide)

Selection optimization:
Loosen p_{T} cuts for Λ^* decaying products
Loosen χ^2_{IP} cuts for kaons

Amplitude analysis

- **Consider Λ as the final-state particle**. The formalism for $\Lambda_b^0 \to J/\psi p K^-$ analysis can be directly used
  - Alignment issue fixed Chinese Phys. C 45 (2021) 063103
- Conventional ΛK^- structures

RBW line shape

State	M_0 (MeV)	Γ_0 (MeV)	LS couplings	J^P examined
$\Xi(1690)^-$	1690 ± 10	< 30	4 (6)	$(1/2, 3/2)^\pm$
$\Xi(1820)^-$	1823 ± 5	24^{+15}_{-10}	3 (6)	$3/2^-$
$\Xi(1950)^-$	1950 ± 15	60 ± 20	3 (6)	$(1/2, 3/2, 5/2)^\pm$
$\Xi(2030)^-$	2025 ± 5	20^{+15}_{-5}	3 (6)	$5/2^\pm$
NR ΛK^-	-	-	4 (4)	$1/2^-$

Significant peaks in $J/\psi\Lambda$ spectrum. Mass & width float

Mass & width constrained using measured values & uncertainties

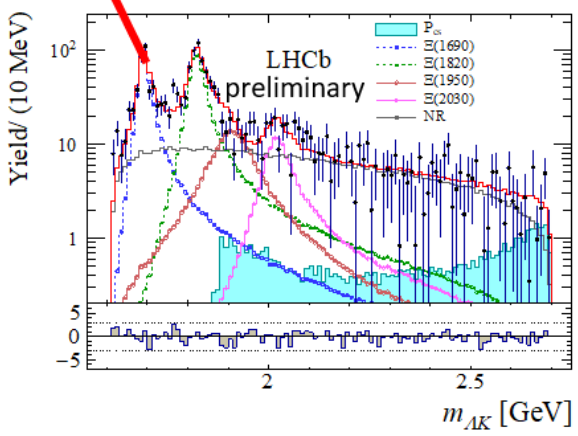
- The potential $J/\psi\Lambda$ state
  - RBW with float mass & width
  - J^P unknown. Tested several hypotheses, use the best one (largest LL) as default setting

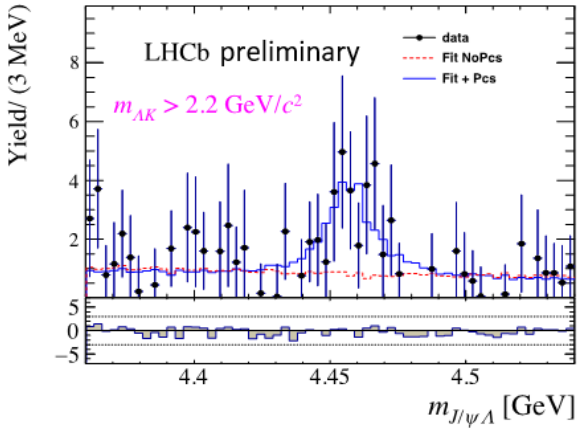
Result of amplitude analysis

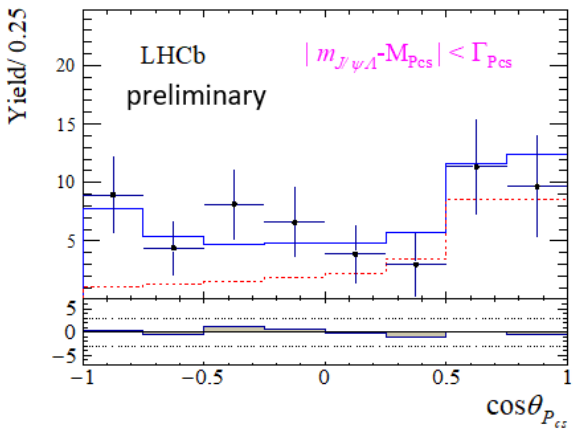
- Adding a P_{cs} improves $-2\ln L$ by 43 units, $\sim 4.3\sigma$ significance
  - **3.1σ significance** when syst. uncertainty considered

Two Ξ^{*-} states

Zooms in to P_{cs} signal region for better visibility







P_{cs} mass 19MeV below the $\Xi_c^0 \overline{D}^{*0}$ threshold. Statistic not enough for J^P determination.

State	M_0 [MeV]	Γ[MeV]
$P_{cs}(4459)^0$	$4458.8 \pm 2.9\,^{+4.7}_{-1.1}$	$17.3 \pm 6.5\,^{+8.0}_{-5.7}$
$\Xi(1690)^-$	$1692.0 \pm 1.3\,^{+1.2}_{-0.4}$	$25.9 \pm 9.5\,^{+14.0}_{-13.5}$
$\Xi(1820)^-$	$1822.7 \pm 1.5\,^{+1.0}_{-0.6}$	$36.0 \pm 4.4\,^{+7.8}_{-8.2}$

Consistent with PDG, with improved precision

Conclusion

- Pentaquark-like states in $\Lambda_b^0 \to J/\psi p K^-$ indicates the existence of a new family of exotic structures

- $\Xi_b^- \to J/\psi \Lambda K^-$ decay observed & studied by LHCb. Evidence of a $J/\psi\Lambda$ structure found in amplitude analysis, which is a candidate of $P_{cs}(udsc\bar{c})$ pentaquark-like state

- Stay tuned with upcoming Run3 data for open questions
  - Further confirm the existence
  - J^P measurement
  - Potential two-peak structure
  - …

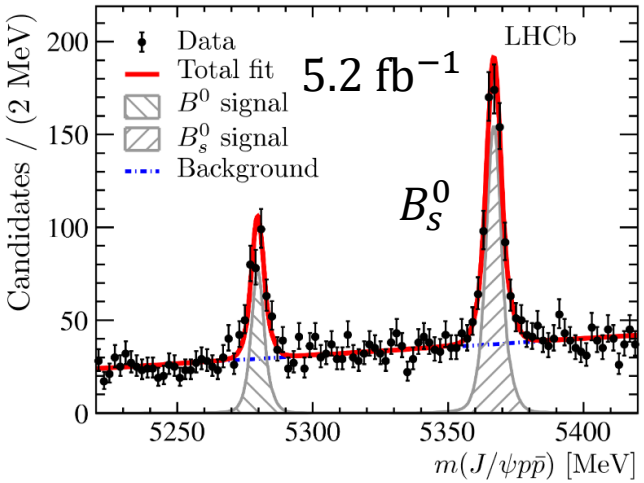
$\Sigma_c \bar{D}^*$ threshold
$\mathrm{P_c}(4450)^+$: $P_c(4440)^+, P_c(4457)^+$

$\Xi_c \bar{D}^*$ threshold
$\boldsymbol{P_{cs}(4459)^+}$**: ? ?**

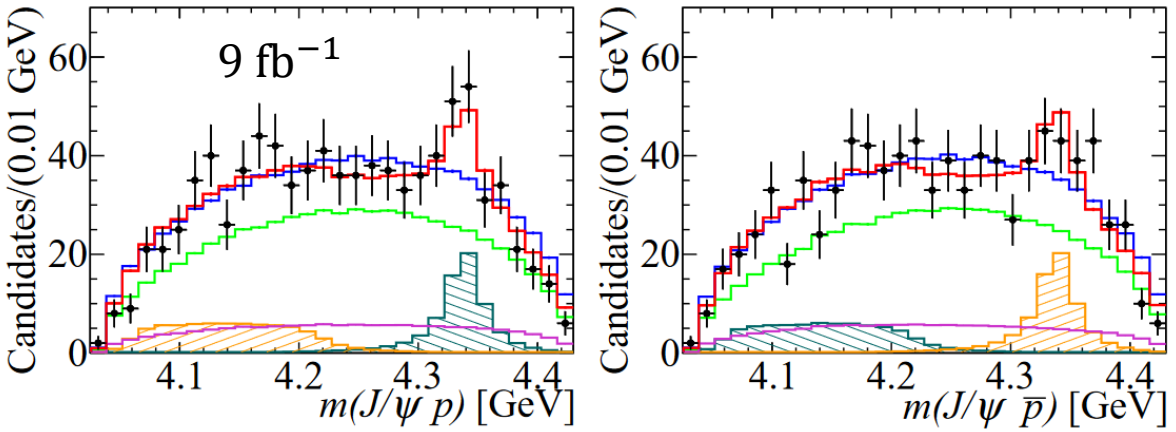
Pentaquark in B meson decays

- A similar story: $B_s^0 \to J/\psi p\bar{p}$
  - Observation of the B decay using part of LHCb pp collision data
  - Non-trivial pentaquark-like structure seen in follow-up Run1+2 study

PRL 122 (2019) 191804



PRL 128 (2021) 062001: $P_c(4337)$

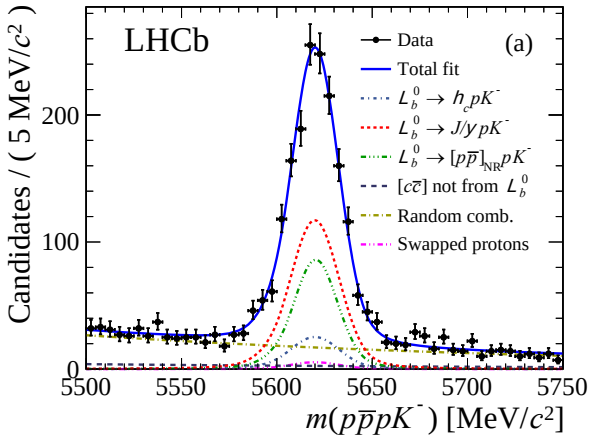


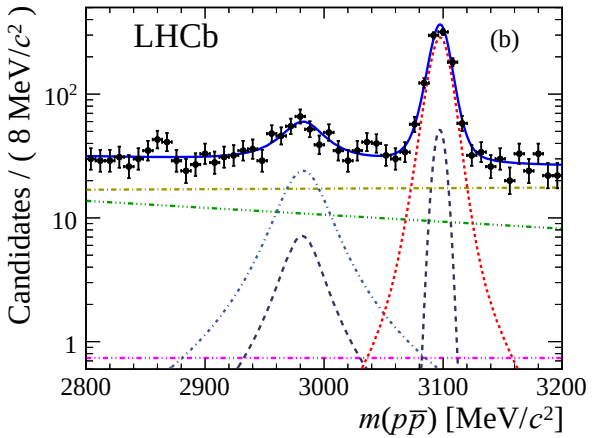
- Now limited by stat. fluctuation. But the **relatively larger P_c fit fraction** make it a promising channel for **precise measurement of J^P, pole position properties**

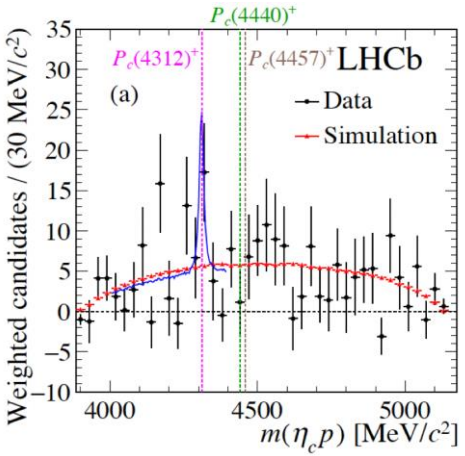
PRD 102 (2020) 112012

Pentaquark in $\eta_c p$ system

- $\sim 170\ \Lambda_b^0 \to \eta_c p K^-$ signals in LHCb Run2 data ($5.5\,\mathrm{fb}^{-1}$)







- Search for $P_c(4312)^+ \to \eta_c p$ but no significant hint
- If $P_c(4312)^+$ is a S-wave $\Sigma_c \bar{D}$ molecular, its fraction in $\Lambda_b^0 \to \eta_c p K^-$ is roughly **3%**
- Yield in Run1~3
  - Run3: $14\ \mathrm{fb}^{-1}$, $\epsilon \times 2$ (fully hadronic) → yield × 5 than Run2
  - A bit more than 1000 $\Lambda_b^0 \to \eta_c p K^-$ signals expected

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Pentaquark in $\eta_c p$ system (prospect)

	$\Xi_b^- \to J/\psi \Lambda K^-$ am. an. (Run1+2, published)	$\Lambda_b^0 \to \eta_c p K^-$ am. an. (Run1~3, proposed)
Yield of b-hadron decays	~1750	~1000
Relative contribution from pentaquark states	~2.7% (measured)	~3% (predicted)
(Expected) achievements	$P_{cs}(4459)^0$ with 3σ, fit fraction reported	Measurement of $P_c(4312)^+$ fit fraction
For J^P determination	not determined. Need Run3 data	not expected. Run4 data would be required.

	P_c $J^P = \frac{1}{2}^-$	P_c $J^P = \frac{3}{2}^-$
L of $\eta_c p$ system	0	2
L of $J/\psi p$ system	0	0, 2

$f(\cos\theta_{P_c}) \sim 1 + 3\cos^2\theta_{P_c}$

$f(\cos\theta_{P_c}) \sim 1$

$f(\cos\theta_{P_c})$ unknown

Thank you for your attention !

Any questions or comments ?