Search for pentaquarks in Λ_b^0 decays

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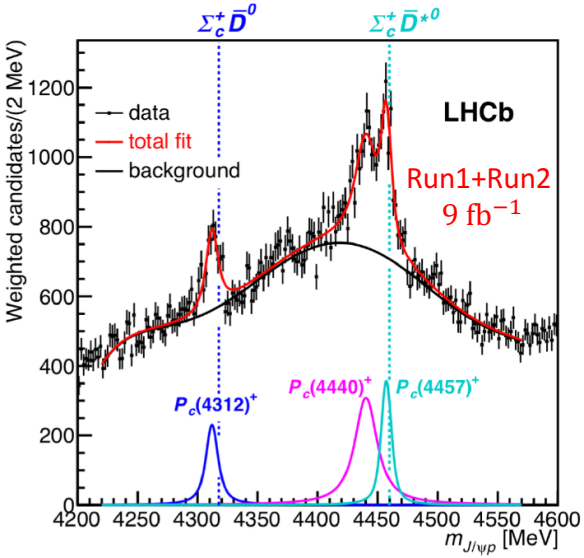
Outline

- Introduction
- Selected topics
  - Observation of $\Lambda_b^0 \to \eta_c p K^-$ and search for $P_c^+ \to \eta_c p$ arXiv:2007.11292. PRD accepted
  - Observation of $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$ LHCb-PAPER-2020-028 in preparation
- Summary

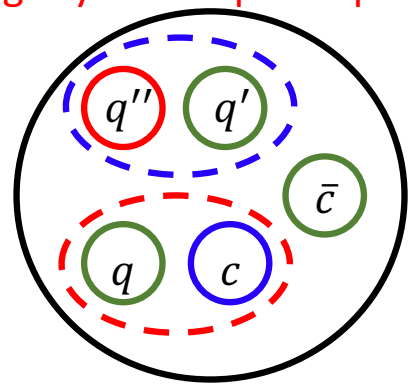
Introduction

- Pentaquarks P_c observed in $\Lambda_b^0 \to J/\psi p K^-$ decays
- The nature of P_c still unknown. Many interpretations…

PRL122(2019)222001

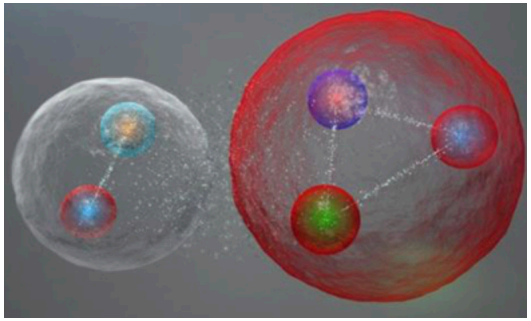


Tightly-bound pentaquark



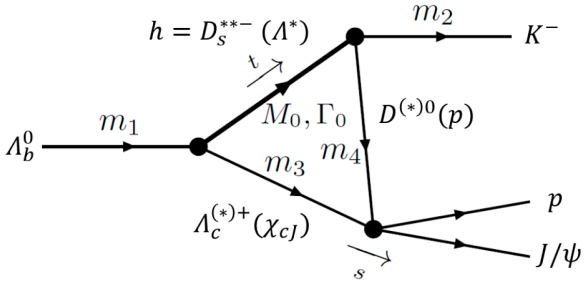
PLB749(2015)289, PLB749(2015)454, etc...

Loosely-bound molecule



PRL105(2010)232001, PRC84(2011)015203, PRL115(2015)122001, etc...

Triangle diagrams



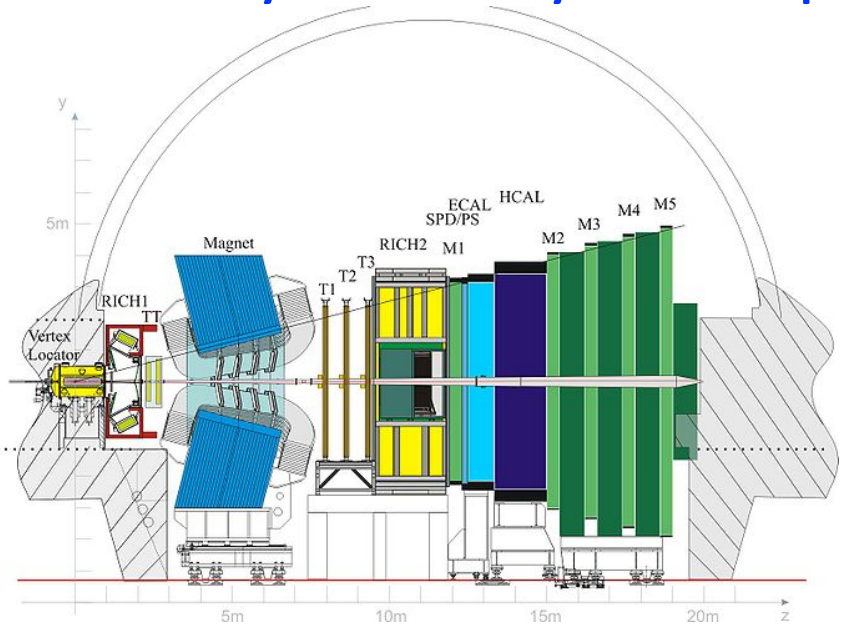
PRD92(2015)071502, PLB757(2016)231, arXiv:1507.06552, PLB757(2016)61, etc

- Search for pentaquarks in other decay modes to improve the knowledge of the pentaquark state
  - Today's menu: search for pentaquarks in Λ_b^0 decays

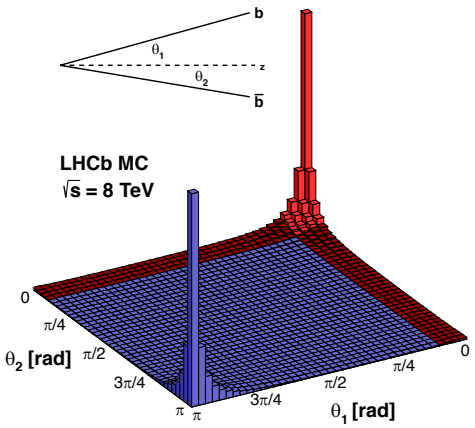
The LHCb detector

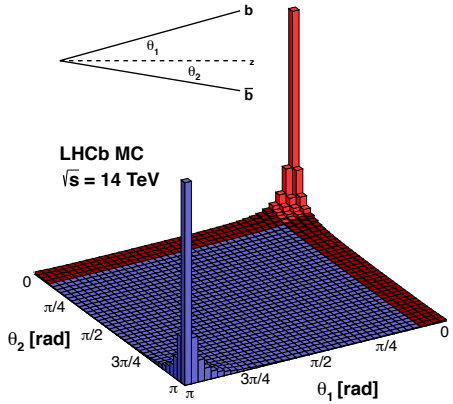
Int. J. Mod. Phys. A 30, 1530022 (2015) JINST 3 (2008) S08005

- Single-arm forward spectrometer, designed for the study of heavy flavor physics



$2 < \eta < 5$ range: ~25% $b\bar{b}$ pairs in LHCb acceptance





Excellent vertex, IP and decay-time resolution:

- $\sigma(\mathrm{IP}) \approx 20$ μm for high-p_{T} tracks
- $\sigma(\tau) \approx 45$ fs for $B_s^0 \to J/\psi\phi$ and $B_s^0 \to D_s^- \pi^+$ decays

Very good momentum resolution

- $\delta p/p \approx 0.5\% - 1\%$ for $p \in (0,200)$GeV
- $\sigma(m_B) \approx 24$ MeV for two-body decays

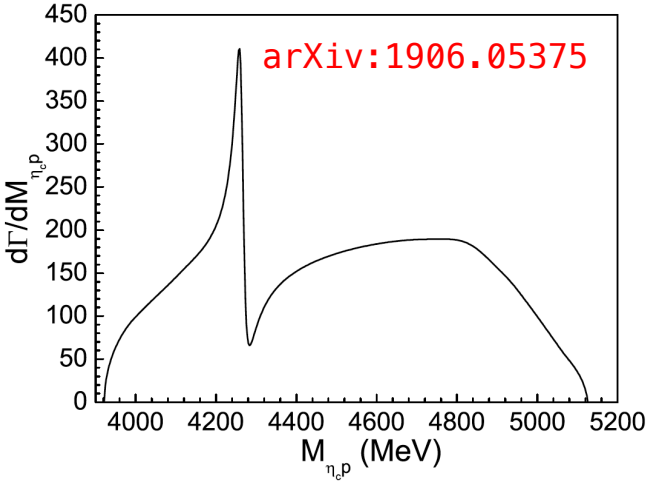
Hadron and Muon identification

- $\epsilon_{K\to K} \approx 95\%$ for $\epsilon_{\pi\to K} \approx 5\%$ up to 100 GeV
- $\epsilon_{\mu\to\mu} \approx 97\%$ for $\epsilon_{\pi\to\mu} \approx 1 - 3\%$

Observation of $\Lambda_b^0 \to \eta_c p K^-$

Motivation

- Same quark contents as $\Lambda_b^0 \to J/\psi p K^-$. Provide unique environment for P_c studies
- Search for new pentaquark:
  - A $\Sigma_c \bar{D}$ molecular state, with predicted mass ~4.27GeV, decaying into $\eta_c p$
- Investigate the nature of observed states
  - If $P_c(4312)^+$ is $\Sigma_c \bar{D}$ molecule



PRD100(2019)034020; PRD100(2019)074007; PRD102(2020)036012

$$\frac{BF(P_c(4312)^+ \to \eta_c p)}{BF(P_c(4312)^+ \to J/\psi p)} \sim 3$$

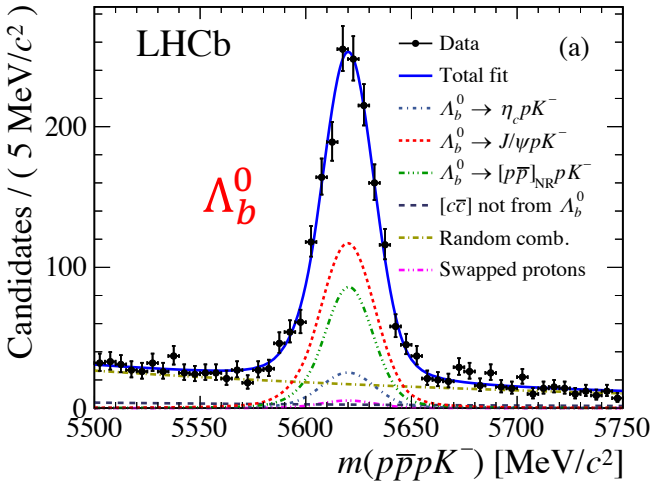
- $\Lambda_b^0 \to \eta_c p K^-$ was not yet observed
- Search for $\Lambda_b^0 \to \eta_c p K^-$, then search for P_c contributions in it

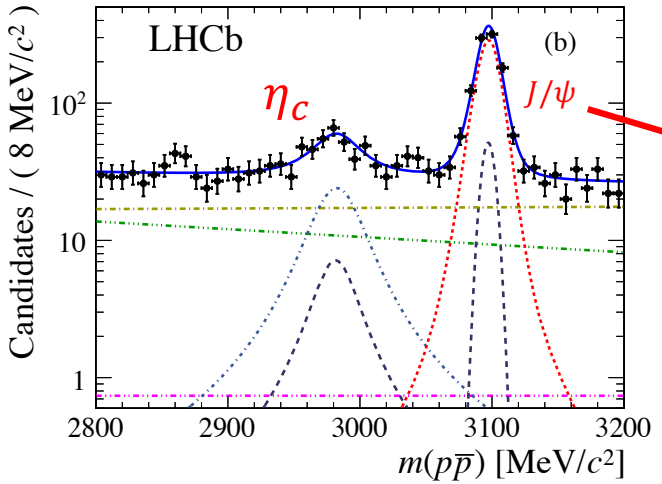
arXiv:2007.11292

Observation of $\Lambda_b^0 \to \eta_c p K^-$

- LHCb run2 data, $\sqrt{s} = 13\text{TeV}$, int. lumi. $\sim 5.5\ \text{fb}^{-1}$
  - η_c reconstructed using $\eta_c \to p\bar{p}$
- Cut-based preselection + Multi-variate analysis for event selection
  - Significant Λ_b^0 flight distance; good track & vertex qualities
  - Positive particle-identification information; hard p, p_T
- Fit 2D mass spectrum to confirm the existence

$\sim 170\ \Lambda_b^0 \to \eta_c p K^-$ signals





$\Lambda_b^0 \to J/\psi p K^-$ used as reference mode for branching fraction measurement

arXiv:2007.11292

Search for the P_c contributions

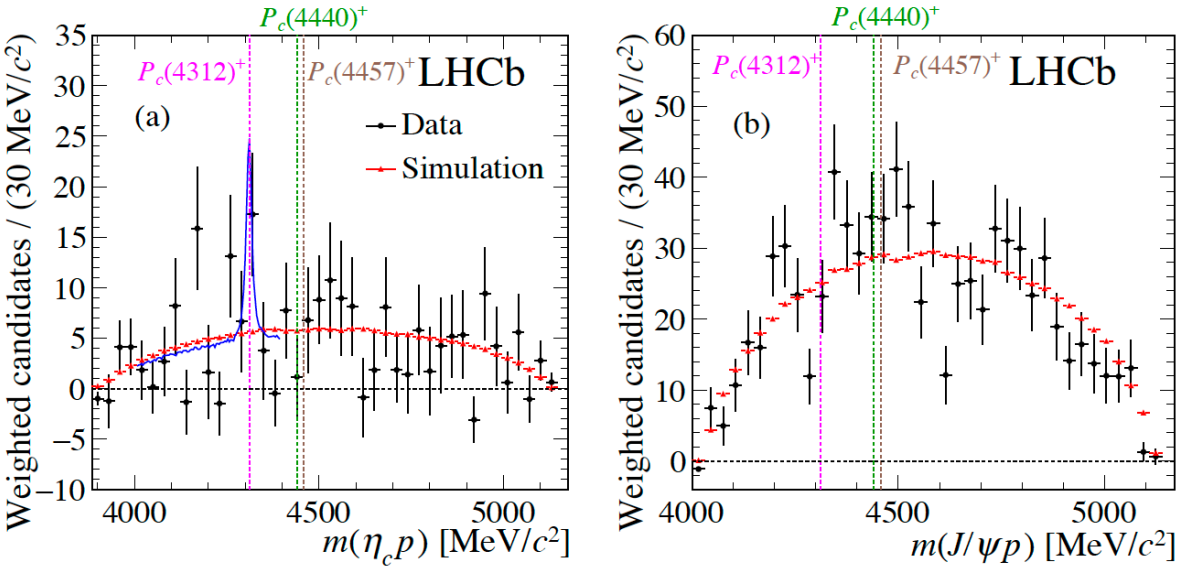
- Check background-subtracted $\eta_c p$ mass spectrum
  - sPlot technique. 2D mass as discriminating variable.

No significant P_c contribution seen in $m(\eta_c p)$ spectrum.

Stay tuned with LHCb upgrade data !

$R(P_c(4312)^+) < 0.24$ @ 95% C. L.

This upper limit is ~8× larger than predictions based on $\Sigma_c \bar{D}$ molecule



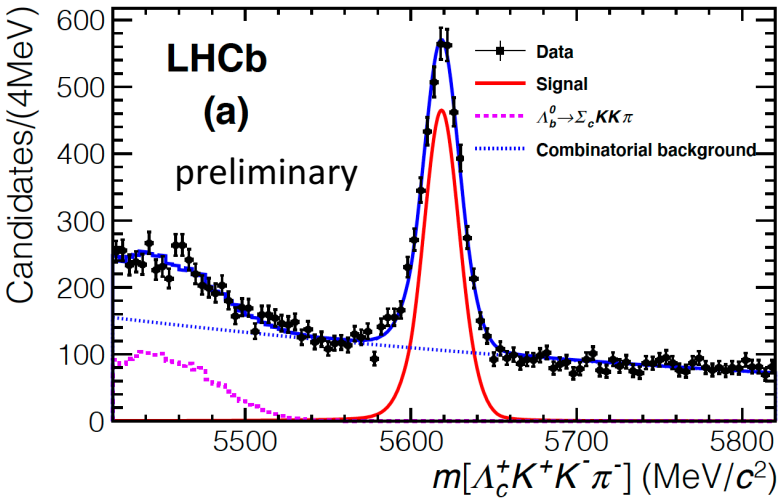
- The $\Lambda_b^0 \to \eta_c p K^-$ branching fraction measured

$$\frac{\mathcal{B}(\Lambda_b^0 \to \eta_c p K^-)}{\mathcal{B}(\Lambda_b^0 \to J/\psi p K^-)} = 0.333 \pm 0.050\ (\text{stat.}) \pm 0.019\ (\text{syst.}) \pm 0.032\ (\mathcal{B})$$

Observation of $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$

Observation of $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$

- A not yet observed decay mode
- Potential open-charm pentaquark in $\Lambda_c^+ K^+$ system
- LHCb run1 data, $\sqrt{s} = 7{,}8$ TeV, int. lumi. $\sim 3\ \mathrm{fb}^{-1}$
  - Λ_c^+ reconstructed using $\Lambda_c^+ \to p K^- \pi^+$
- Cut-based preselection + Multi-variate analysis for event selection
- Λ_b^0 mass fit for the observation
  - Signal: double-sided CB function
  - Combinatorial background: exponential function
  - Partially reconstructed $\Lambda_b^0 \to \Sigma_c^+ K^+ K^- \pi^-$

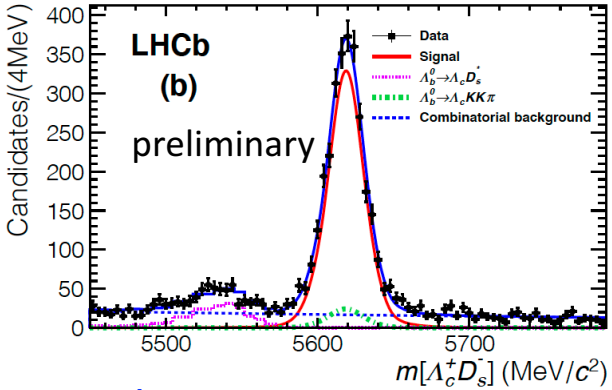


$$N\left(\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-\right) = 3400 \pm 80$$

Branching fraction measurement

- $\Lambda_b^0 \to D_s^- \Lambda_c^+, D_s^- \to K^+K^-\pi^-$ as normalization channel

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)} = \frac{N(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-)}{N(\Lambda_b^0 \to \Lambda_c^+ D_s^-[K^+K^-\pi^+])} \times \frac{\epsilon_{\rm tot}(\Lambda_b^0 \to \Lambda_c^+ D_s^-[K^+K^-\pi^+])}{\epsilon_{\rm tot}(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-)} \times \mathcal{B}(D_s^- \to K^+K^-\pi^-),$$



Fit $m(\Lambda_b^0)$ for raw yield estimation

Use simulation for efficiency calculation, with necessary data-driven tunings

$$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ D_s^-)} = (9.26 \pm 0.29 \pm 0.46 \pm 0.26) \times 10^{-2},$$

stat. syst. ext.

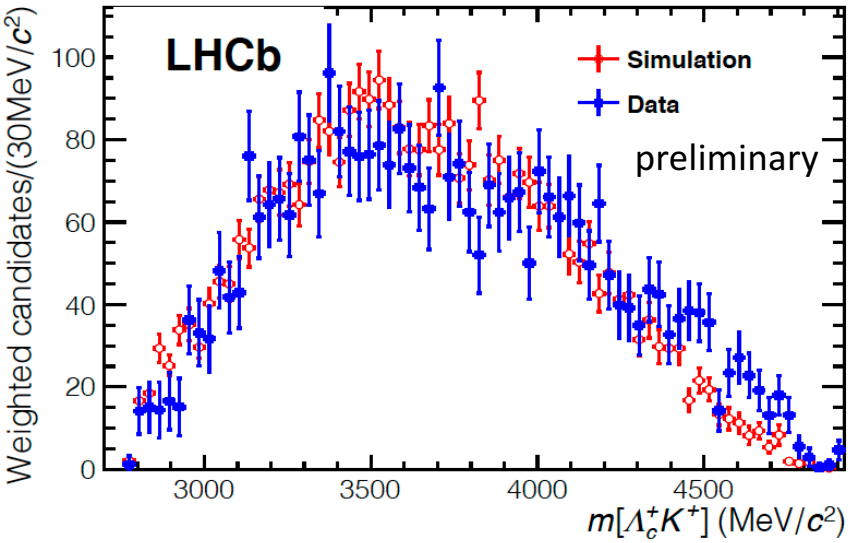
$$\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+ K^+K^-\pi^-) = (1.02 \pm 0.03 \pm 0.05 \pm 0.10) \times 10^{-3}$$

Systematic uncertainty dominated by imperfect knowledge of the phase-space distribution of the 4-body Λ_b^0 decay

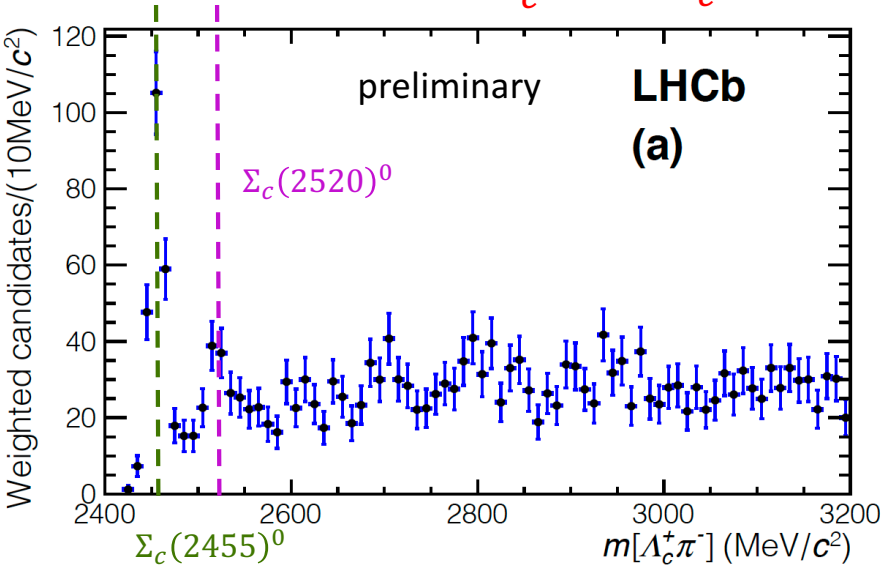
Resonant contributions

- Background-subtracted mass spectrum of final-state combinations
  - sPlot technique. $m(\Lambda_b^0)$ as discriminating variable.

No excess observed in $m(\Lambda_c^+ K^+)$ spectrum



Contributions from $\Sigma_c^{(*)0} \to \Lambda_c^+ \pi^-$ seen



Conclusion

- LHCb made the observation of several Λ_b^0 decays, which is promising for pentaquark studies in the future
  - $\Lambda_b^0 \to \eta_c p K^-$
  - $\Lambda_b^0 \to \Lambda_c^+ K^+ K^- \pi^-$
- No P_c contribution observed at this stage. But stay tuned with LHCb upgrade data available !

Thank you for your attention !
Any questions or comments ?