Measurements of branching ratios of b-hadrons at the LHCb detector

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Based on analyses by the LHCb Collaboration:
First observations of $B_s^0 \to D^+D^-$, $D_s^+D^-$ and $D^0\bar{D}^0$ decays, Phys. Rev. D 87, 092007 (2013),
Observation of the $B^0 \to \bar{D}^{*0}K^+\pi^-$ and $B_s^0 \to \bar{D}^{*0}K^-\pi^+$ decays, Phys. Rev. D 105, 072005 (2022),
Observation of $\Lambda_b^0 \to D^+p\pi^-\pi^-$ and $\Lambda_b^0 \to D^{*+}p\pi^-\pi^-$ decays, JHEP 03 153 (2022).

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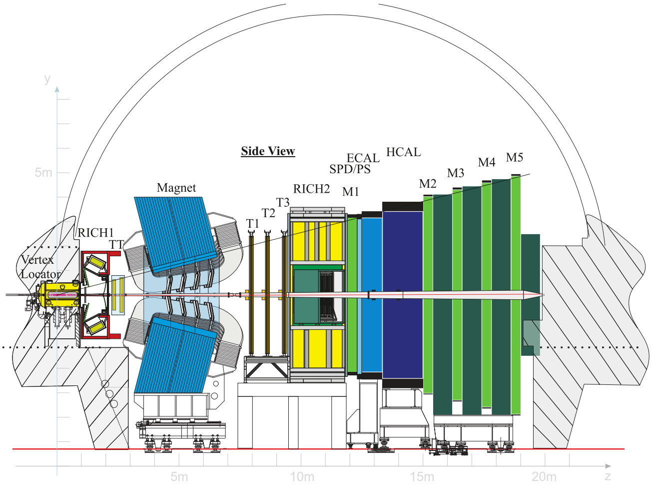
Introduction

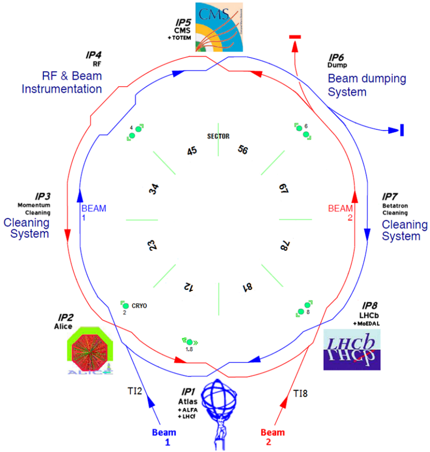
Measurements of nonleptonic b-hadron decays allow one to

- Probe the CKM Matrix parameters: determine transition rates between quarks,
- Study final state interactions,
- Test theoretical calculations: perturbative, non-perturbative, phenomenological,
- Improve our knowledge of hadron spectroscopy.

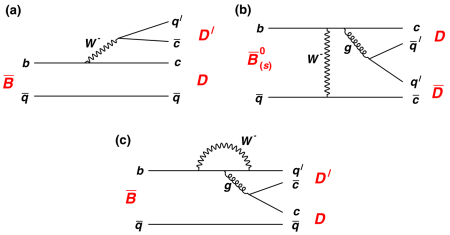
The γ of the CKM matrix is of especially high priority in modern particle physics. Its measurement can be improved by investigating both larger data samples and new decays.

The LHCb detector at the LHC

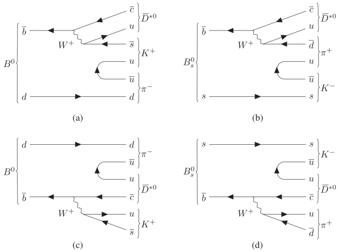




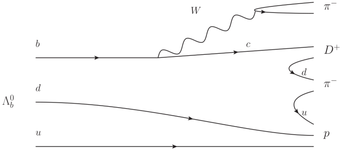
The decays under the study



$B \to D\bar{D}$ decays



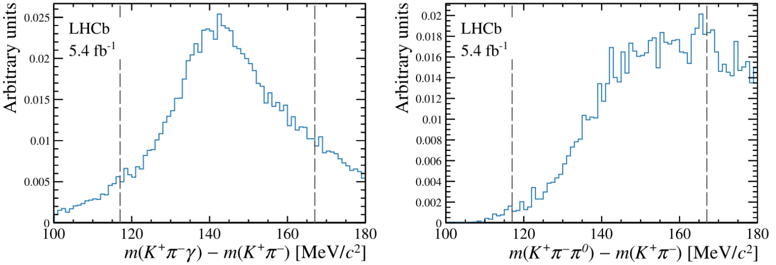
$B \to \bar{D}^{*} K\pi$ decays



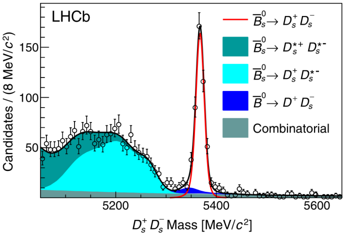
$\Lambda_b^0 \to D^{(*)+} p \pi^- \pi^-$ decays

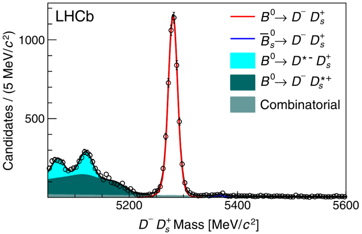
Event selection

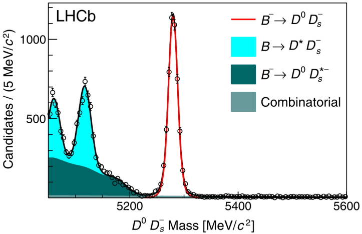
- Cuts on kinematic variables: p_T, η, distance from the pp interaction, . . . ,
- Cuts on particle identification parameters,
- Exclusion of specific troublesome events,
- A neural network is used to further improve signal quality.

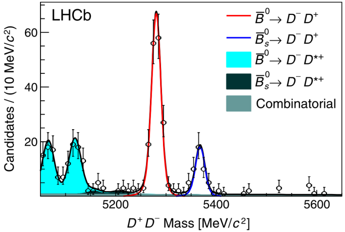


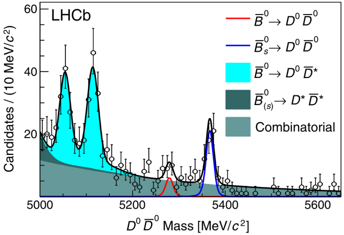
Invariant mass spectrum model and fit: $B \to D\bar{D}$ decays





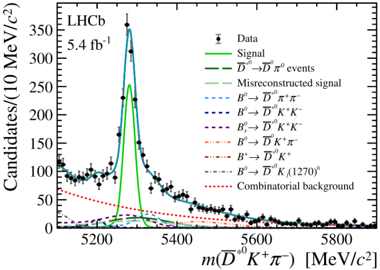


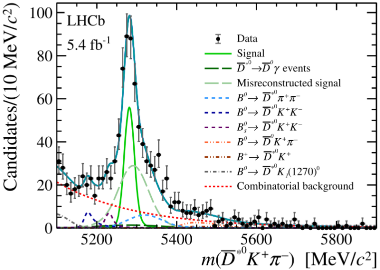


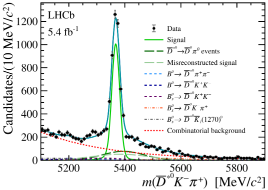


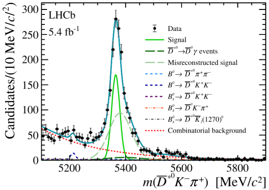
Normalization

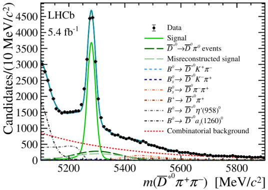
Invariant mass spectrum model and fit: $B \to \bar{D}^* K \pi$ decays

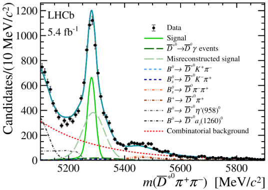












Invariant mass spectrum model and fit: $\Lambda_b^0 \to D^{(*)+} p \pi^- \pi^-$ decay

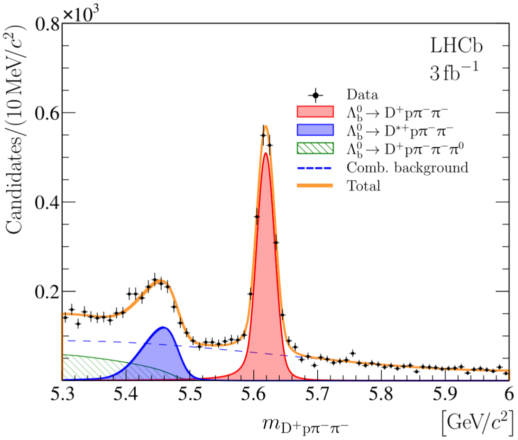


Figure 1: Mass distribution for selected $\Lambda_b^0 \to D^+ p\pi^-\pi^-$ candidates. The projection of an unbinned likelihood fit, described in the text, is superimposed.

Signal

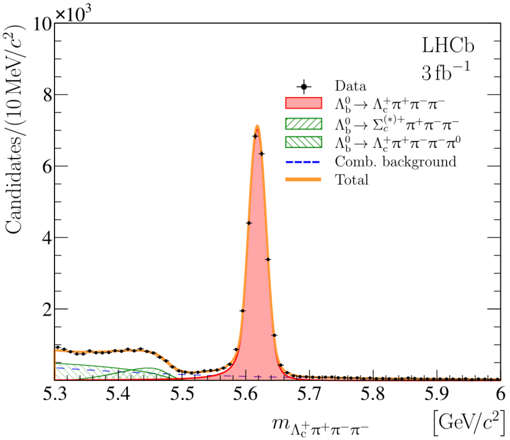
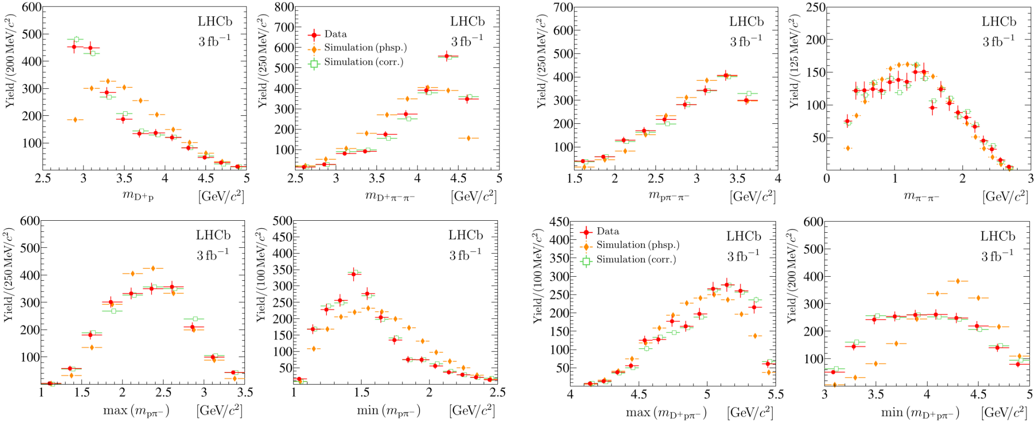


Figure 2: Mass distribution for selected $\Lambda_b^0 \to \Lambda_c^+ \pi^+\pi^-\pi^-$ candidates. The projection of an unbinned likelihood fit, described in the text, is superimposed.

Normalization

Corrections for the effects of the selection: efficiencies



Systematic uncertainties

The largest sources if systematic uncertainty are

- the fitting model,
- the approach to combining results with different secondary decays,
- the finite size of the simulation,
- the approach to excluding unwanted events like duplicates,
- the limited knowledge of constants.

The total systematic uncertainty of the branching ratios ranges from 3% to 12% for different decays.

Results: branching ratios of the B and Λ_b^0 decays

$$\frac{\mathcal{B}(\bar{B}_s^0 \to D^+ D^-)}{\mathcal{B}(\bar{B}^0 \to D^+ D^-)} = 1.08 \pm 0.20(\text{stat}) \pm 0.10(\text{syst}),$$

$$\frac{\mathcal{B}(\bar{B}_s^0 \to D_s^+ D^-)}{\mathcal{B}(B^0 \to D^- D_s^+)} = 0.050 \pm 0.008(\text{stat}) \pm 0.004(\text{syst}),$$

$$\frac{\mathcal{B}(\bar{B}_s^0 \to D^0 \bar{D}^0)}{\mathcal{B}(B^- \to D^0 D_s^-)} = 0.019 \pm 0.003(\text{stat}) \pm 0.003(\text{syst}),$$

$$\frac{\mathcal{B}(\bar{B}^0 \to D^0 \bar{D}^0)}{\mathcal{B}(B^- \to D^0 D_s^-)} = 0.0014 \pm 0.0006(\text{stat}) \pm 0.0002(\text{syst})$$

$$[<0.0024 \quad \text{at } 90\% \text{ CL}],$$

$$\frac{\mathcal{B}(\bar{B}_s^0 \to D_s^+ D_s^-)}{\mathcal{B}(B^0 \to D^- D_s^+)} = 0.56 \pm 0.03(\text{stat}) \pm 0.04(\text{syst}),$$

$$\frac{\mathcal{B}(B^- \to D^0 D_s^-)}{\mathcal{B}(B^0 \to D^- D_s^+)} = 1.22 \pm 0.02(\text{stat}) \pm 0.07(\text{syst}).$$

$$\frac{\mathcal{B}(B^0 \to \bar{D}^{*0} K^+ \pi^-)}{\mathcal{B}(B^0 \to \bar{D}^{*0} \pi^+ \pi^-)} = 0.0836 \pm 0.0043 \pm 0.0061,$$

$$\frac{\mathcal{B}(B_s^0 \to \bar{D}^{*0} K^- \pi^+)}{\mathcal{B}(B^0 \to \bar{D}^{*0} \pi^+ \pi^-)} = 1.178 \pm 0.029 \pm 0.091 \pm 0.037,$$

$$\frac{\mathcal{B}(B^0 \to \bar{D}^{*0} K^+ \pi^-)}{\mathcal{B}(B_s^0 \to \bar{D}^{*0} K^- \pi^+)} = 0.0712 \pm 0.0035 \pm 0.0065 \pm 0.0022,$$

$$\frac{\mathcal{B}\left(\Lambda_b^0 \to D^+ p \pi^- \pi^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to \Lambda_c^+ \pi^+ \pi^- \pi^-\right)} \times \frac{\mathcal{B}\left(D^+ \to K^- \pi^+ \pi^+\right)}{\mathcal{B}\left(\Lambda_c^+ \to p K^- \pi^+\right)} = \\ = (5.35 \pm 0.21 \pm 0.16)\%$$

$$\frac{\mathcal{B}\left(\Lambda_b^0 \to D^{*+} p \pi^- \pi^-\right)}{\mathcal{B}\left(\Lambda_b^0 \to D^+ p \pi^- \pi^-\right)} \times \mathcal{B}\left(D^{*+} \to D^+ \pi^0,\ D^+ \gamma\right) = \\ = (61.3 \pm 4.3 \pm 4.0)\%$$

Conclusion

- First observation of $\bar{B}_s^0 \to D^+D^-$, $\bar{B}_s^0 \to D_s^+D^-$, $\bar{B}_s^0 \to D^0\bar{D}^0$, $\Lambda_b^0 \to D^+p\pi^-\pi^-$, $\Lambda_b^0 \to D^{*+}p\pi^-\pi^-$.
- Measurements of $\bar{B}_s^0 \to D_s^+D_s^-$, $B_s^- \to D^0D_s^-$.
- The measurements of the $B \to D\bar{D}$ decays favor the perturbative QCD predictions, not phenomenological ones.
- The studied $B \to \bar{D}^*K\pi$ decays have large significances (over 5σ).
  The results and the extracted final state particle distributions will be very useful for future CKM γ angle measurements.
- BRs of the Λ_b^0 baryon give a very similar ratio of D and D^* mesons compared to ee annihilation. The hadronization must be the very similar.

Conclusion

- First observation of $\bar{B}_s^0 \to D^+D^-$, $\bar{B}_s^0 \to D_s^+D^-$, $\bar{B}_s^0 \to D^0\bar{D}^0$, $\Lambda_b^0 \to D^+p\pi^-\pi^-$, $\Lambda_b^0 \to D^{*+}p\pi^-\pi^-$.
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Thank you!