# Observation of the decay $\Xi_b^- \to pK^-K^-$

arXiv:1612.02244
Phys. Rev. Lett. 118 (2017) 071801

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**On behalf of the LHCb Collaboration**

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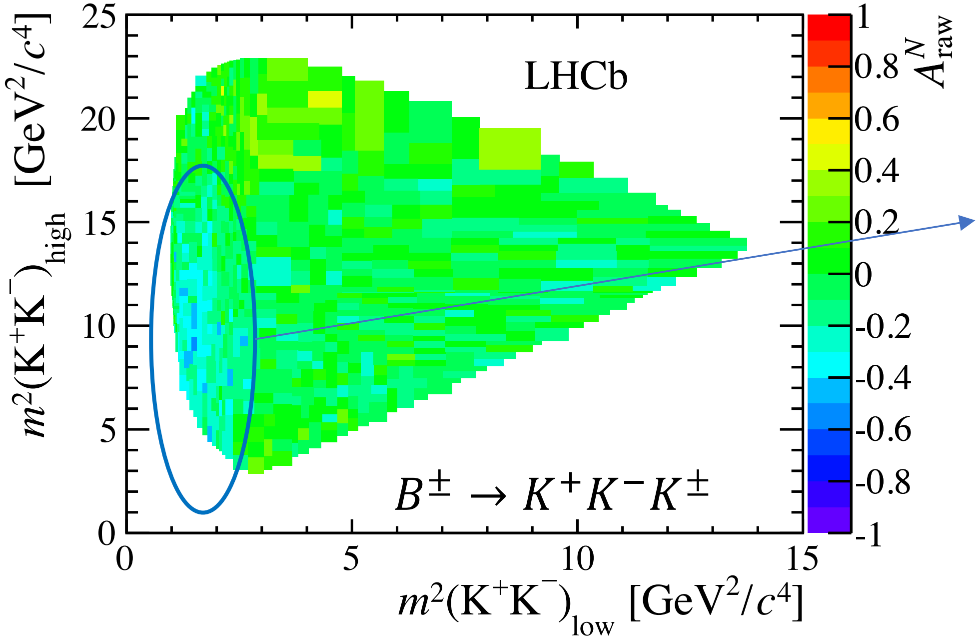
# Charmless hadronic decays

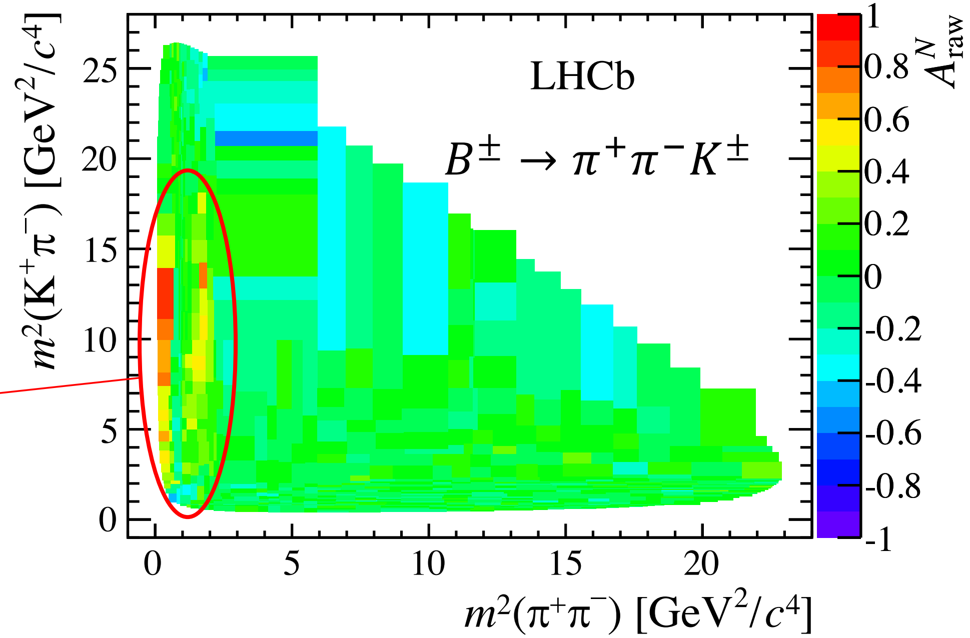
- Decays proceed via $b \to u$ and $b \to d$ or $b \to s$ transitions at tree and loop level respectively.
- Large local CP asymmetries ($\mathcal{A}_{CP}$) observed in $B^{\pm} \to \pi^{+}\pi^{-}\pi^{\pm}$, $B^{\pm} \to K^{+}K^{-}\pi^{\pm}$, $B^{\pm} \to \pi^{+}\pi^{-}K^{\pm}$ and $B^{\pm} \to K^{+}K^{-}K^{\pm}$ decays.

Phys. Rev. Let. 111 (2013) 101801
Phys. Rev. Let. 112 (2014) 011801
Phys. Rev. D90 (2014) 112004




Large negative asymmetries

Large positive asymmetries



# Charmless hadronic decays of b-baryons

**CDF** — $\Lambda_b^0 \to p h^-$

Phys. Rev. Lett. 113 (2014) 242001

$\mathcal{A}_{CP}(\Lambda_b^0 \to p\pi^-) = +0.06 \pm 0.07\,(stat) \pm 0.03\,(syst)$
$\mathcal{A}_{CP}(\Lambda_b^0 \to pK^-) = -0.10 \pm 0.08\,(stat) \pm 0.04\,(syst)$

**LHCb** — $\Lambda_b^0(\Xi_b^0) \to K_s p h^-$

JHEP 04 (2014) 087

$\mathcal{A}_{CP}(\Lambda_b^0 \to K_s^0 p\pi^-) = 0.22 \pm 0.13\,(stat) \pm 0.03\,(syst)$

**LHCb** — $\Lambda_b^0(\Xi_b^0) \to \Lambda h^+ h^-$

JHEP 05 (2016) 081

$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+\pi^-) = -0.53 \pm 0.23\,(stat) \pm 0.11\,(syst)$
$\mathcal{A}_{CP}(\Lambda_b^0 \to \Lambda K^+K^-) = -0.28 \pm 0.10\,(stat) \pm 0.07\,(syst)$

**LHCb** — $\Lambda_b^0 \to \Lambda\eta, \Lambda\phi$

JHEP 09 (2015) 006
Phys. Lett. B 759 (2016) 282

Evidence of $\Lambda\eta$ final state. Observed $\Lambda\phi$ final state at $5.9\sigma$ with triple-product asymmetries consistent with zero.

Consistent with CP symmetry

Where $h \in \{\pi, K\}$ from this point forward.

**LHCb** — $\Lambda_b^0(\Xi_b^0) \to p h^- h^- h^+$

Nat. Phys. (2017)

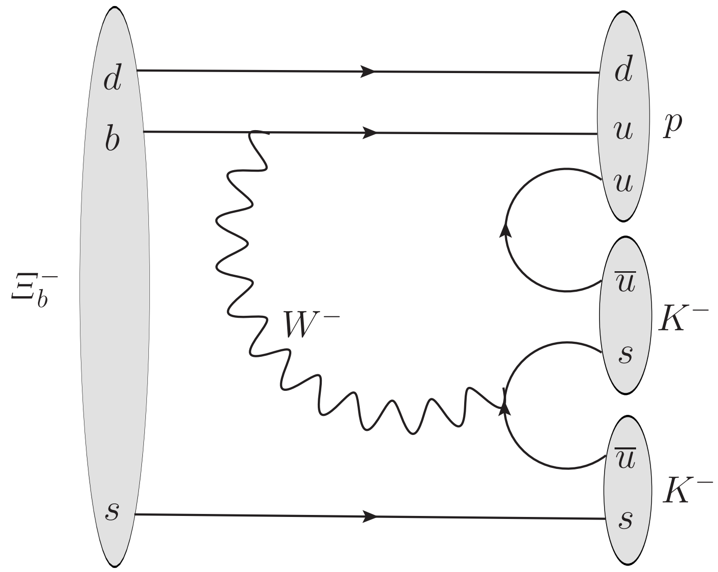
1st evidence of CP Violation (CPV) in baryons. **See Giulio's plenary talk on "Charmless b-hadron decays at LHCb" on Friday**.

# Charmless hadronic decays of $\Xi_b^-$ and $\Omega_b^-$ baryons

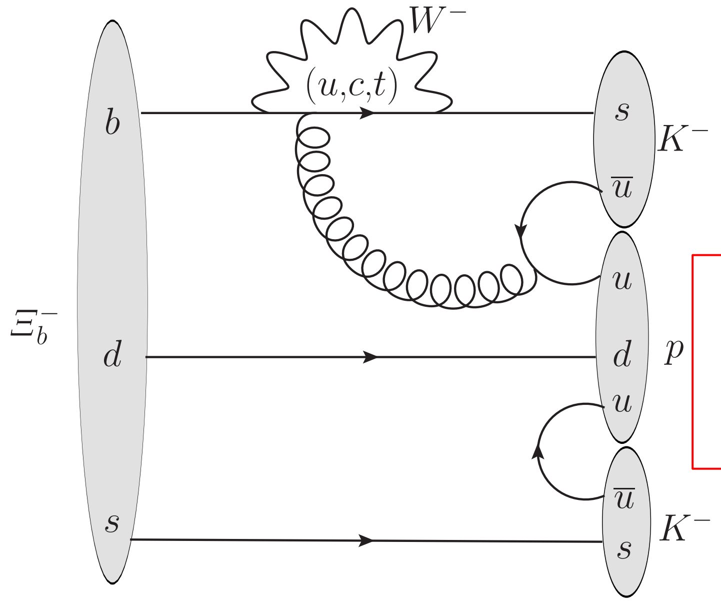
- No charmless decays of strange-beauty baryons have been observed until now.
- In this analysis, we conduct search for $\Xi_b^-$ and $\Omega_b^-$ baryon decays to charmless hadronic final states i.e. $\Xi_b^-(\Omega_b^-) \rightarrow ph^-h^-$.
- Topology of these baryon decays similar to that of previously mentioned $B^{\pm}$ decays. Interesting to see if large CP violation effects are also seen in b-baryon decays.
- No experimental or theoretical results on $\mathfrak{B}(\Xi_b^-(\Omega_b^-) \rightarrow ph^-h^-)$ existed prior to this analysis.

# Charmless hadronic decays of $\Xi_b^-$ and $\Omega_b^-$ baryons

- The $\Xi_b^- \to pK^-K^-$ decay is Cabibbo-suppressed at tree ($b \to u$) and loop ($b \to s$) level.
- The $\Omega_b^- \to pK^-K^-$ and $\Xi_b^- \to pK^-\pi^-$ proceed at tree and loop level via $b \to u$ and $b \to d$ transitions.
- Other decays i.e. $\Xi_b^-(\Omega_b^-) \to p\pi^-\pi^-$ and $\Omega_b^- \to pK^-\pi^-$ are expected to be even further suppressed.
- Compared to $\Xi_b^-$ baryons, fewer $\Omega_b^-$ baryons are produced in the pp collisions but relative fragmentation fractions, $f$ , are not measured.




$$\propto V_{ub}V_{us}^* \approx \lambda^4$$




$$\propto \sum_{u,c,t} V_{xb}V_{xs}^* \approx \lambda^2$$

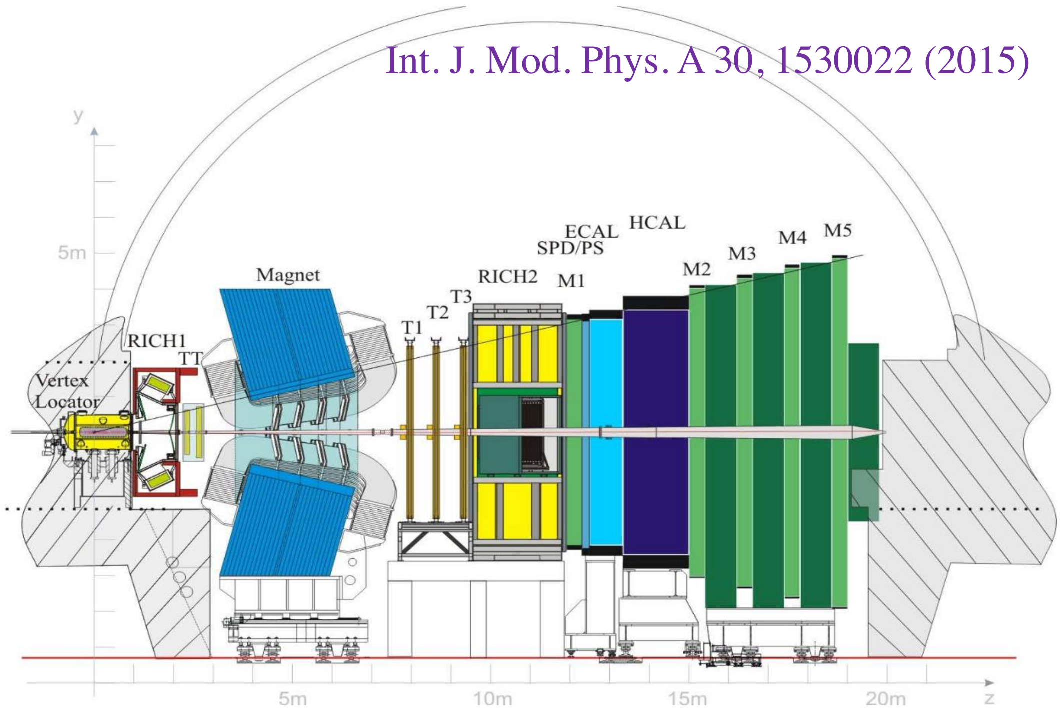
# The Large Hadron Collider beauty (LHCb) Experiment

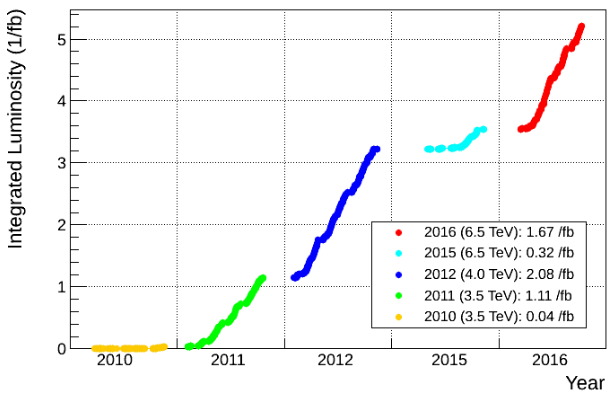
- Forward spectrometer ($2 < \eta < 5$) optimized for b- and c- hadron physics.
- The b-baryons are produced at unprecedented quantities at LHCb. Most precise measurements of mass and lifetime of $\Xi_b^0$, $\Xi_b^-$ and $\Omega_b^-$ were made.

Phys. Rev. Lett. 113 (2014) 032001
Phys.Rev.Lett. 113 (2014) 242002
Phys. Rev. D93 (2016) 092007

- Excellent performance:
  - Impact parameter (IP) resolution: $\sigma_{IP} \approx 20\ \mu m$ (at high $p_T$).
  - Decay time resolution: $\sigma_t \approx 50\ fs$.
  - Momentum resolution: $\frac{\sigma_p}{p} \approx 0.5 - 0.8\ \%$ (p < 100 GeV/c)
  - Particle Identification (PID): $\epsilon(K) \approx 95\%$, Mis-ID $\epsilon(\pi \to K) \approx 5\%$ ($p$ < 100 GeV/c).

Int. J. Mod. Phys. A 30, 1530022 (2015)




$$\int \mathcal{L}\, dt = 5.22\ \text{fb}^{-1}$$

# Analysis Strategy

- Measure the relative product of branching fraction and fragmentation fraction with $B^- \to K^+K^-K^-$ as the normalisation mode.

$$R_{\Xi_b^-(\Omega_b^-)\to ph^-h'^-} = \frac{f_{\Xi_b^-(\Omega_b^-)}}{f_u} \times \frac{\mathfrak{B}(\Xi_b^-(\Omega_b^-) \to p\,h^-h'^-)}{\mathfrak{B}(B^- \to K^+K^-K^-)} = \frac{N(\Xi_b^-(\Omega_b^-) \to p\,h^-h'^-)}{N(B^- \to K^+K^-K^-)} \times \frac{\epsilon(B^- \to K^+K^-K^-)}{\epsilon(\Xi_b^-(\Omega_b^-) \to p\,h^-h'^-)}$$

- We use 3 $\text{fb}^{-1}$ of data collected by LHCb during 2011 and 2012.
- Conduct signal selection to improve the purity of the sample and obtain the efficiency of the selection.
- Charmless signal regions were not inspected until the selection was finalised.
- To extract the signal yield conduct a simultaneous unbinned maximum likelihood fit to the invariant mass of each $h^-h^-p$ final state.

# Signal Selection and Efficiency

- Online selection, performed with standard LHCb trigger algorithms, and offline event selection was performed to select signal-like candidates. J. Instrum. 8, P04022 (2013)
- Neural networks were trained to reduce the combinatorial background.
- Particle identification (PID) criteria were used to reduce the contribution from backgrounds that arise due to the mis-identification of one or more final state tracks.
- For the normalisation mode, contribution from $B^- \to D^0(\to K^+K^-)K^-$ was vetoed and for signal modes, possible contribution from the as yet unobserved mode of $\Xi_b^- \to \Xi_c^0(\to ph^-)h^-$ was vetoed.

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- The efficiency of signal selection was obtained from simulation except for efficiency of PID requirement which is obtained using a data-driven method. LHCb-PUB-2016-021
- Variation of efficiency over phase-space introduced by the acceptance and signal selection was accounted for in the BF ratio calculation.

# Signal Yield Extraction

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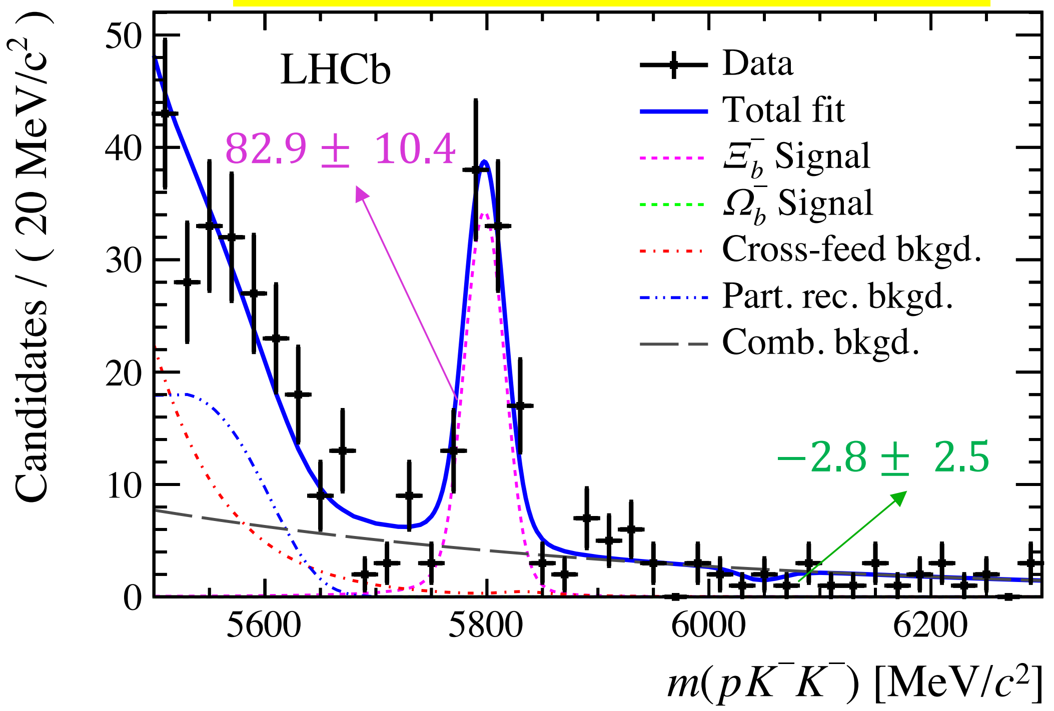
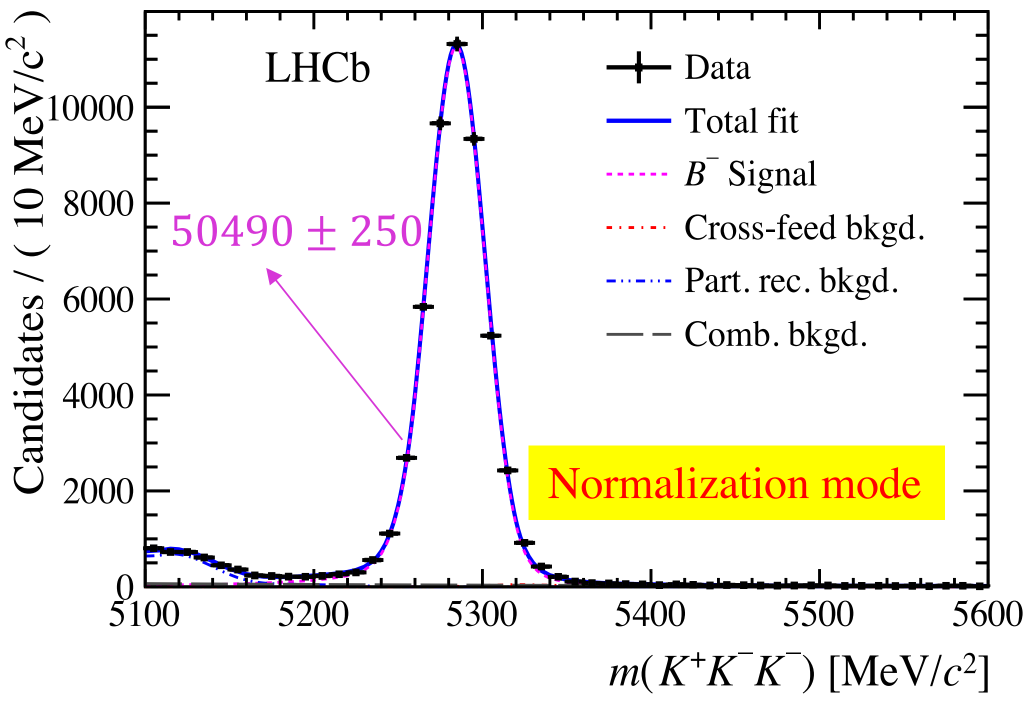
- Shape parameters of PDF fixed either to known values or determined from simulation.
- Some data-simulation differences are determined from the normalization mode and used in signal shape.
- Cross-feed backgrounds arise from mis-identification of final state tracks - rates constrained from mis-ID probabilities determined from data control samples.

Observation of $\Xi_b^- \to pK^-K^-$ at 8.7 $\sigma$



# Signal Yield Extraction

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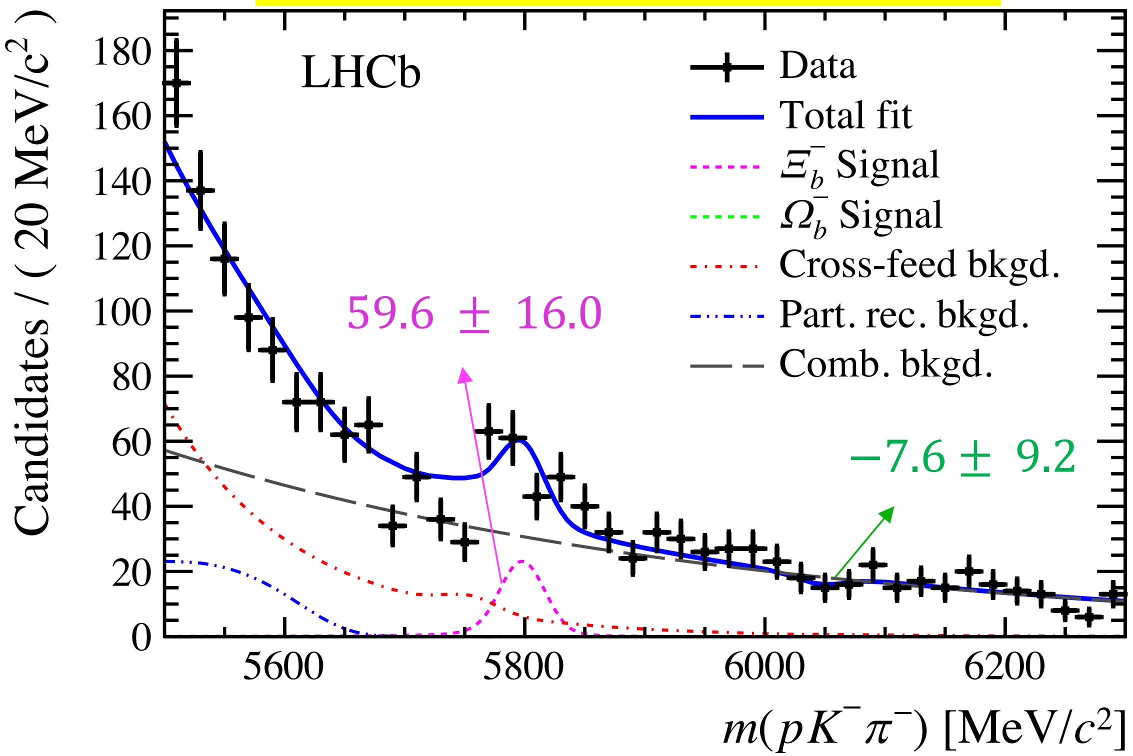
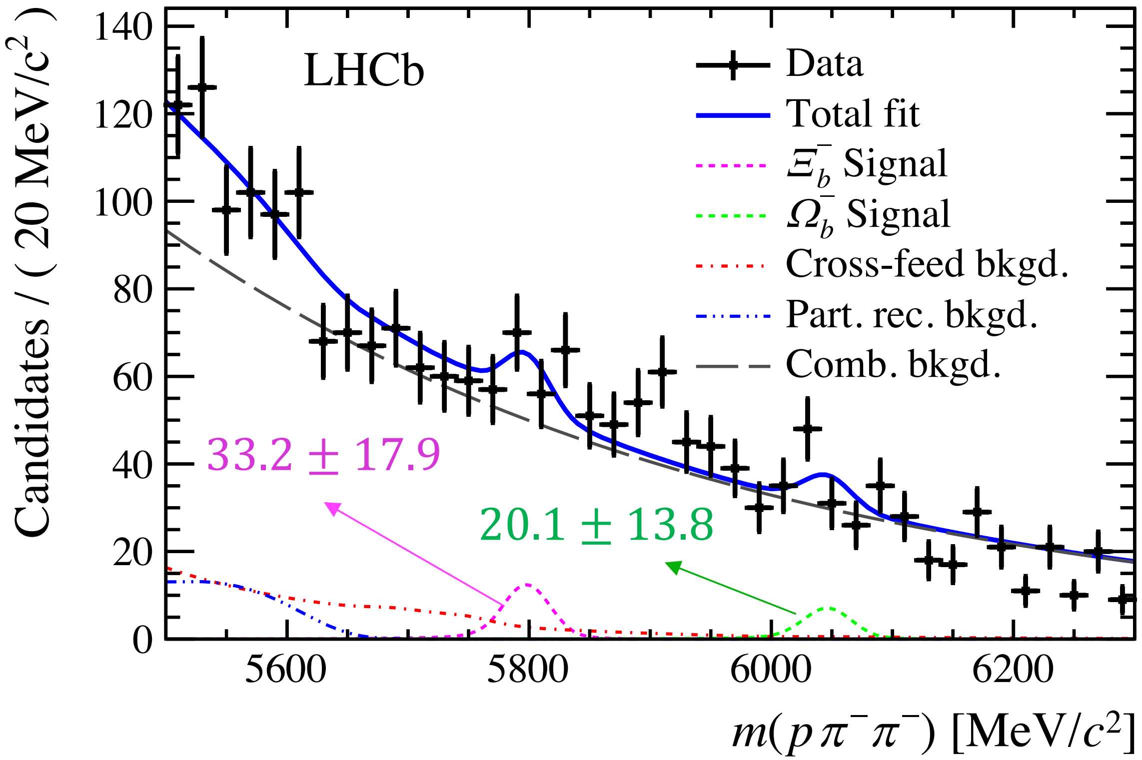
- The partially reconstructed background consists of $\Xi_b^- \to N(p\pi^0)h^-h^-$.
- No evidence of $\Xi_b^- \to p\pi^-\pi^-$ and $\Omega_b^- \to ph^-h^-$ decays .

Evidence of $\Xi_b^- \to pK^-\pi^-$ at 3.4 $\sigma$



# Evaluation of Systematic Uncertainty

- Sources of systematic uncertainties arising from fit model and efficiency are investigated.
- For modes observed with significance $> 3\,\sigma$, the dominant source of systematic uncertainty arises due to the mis-match of $\Xi_b^-$ production kinematics in simulation and data.
- For modes observed with significance $< 3\,\sigma$, the dominant source of systematic uncertainty arises from variation of the efficiency over the phase space.
- We also measure $\frac{\mathfrak{B}(\Xi_b^- \to pK^-\pi^-)}{\mathfrak{B}(\Xi_b^- \to pK^-K^-)}$ and $\frac{\mathfrak{B}(\Xi_b^- \to p\pi^-\pi^-)}{\mathfrak{B}(\Xi_b^- \to pK^-K^-)}$. For these, the dominant source of systematic uncertainty arises from the residual differences between data and simulation in the trigger, fit model and for the $\Xi_b^- \to p\pi^-\pi^-$ mode from efficiency variation across the phase space.

# Results

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$$R_{\Xi_b^- \to pK^-K^-} = \left(265 \pm 35(stat) \pm 47(syst)\right) \times 10^{-5}$$

Observation at 8.7 $\sigma$

$$R_{\Xi_b^- \to pK^-\pi^-} = \left(259 \pm 64(stat) \pm 49(syst)\right) \times 10^{-5}$$

Evidence at 3.4 $\sigma$

$$\frac{\mathfrak{B}(\Xi_b^- \to pK^-\pi^-)}{\mathfrak{B}(\Xi_b^- \to pK^-K^-)} = 0.98 \pm 0.27\ (stat) \pm 0.09\ (syst)$$

$$R_{\Xi_b^- \to p\pi^-\pi^-} < 147\ (166) \times 10^{-5}$$

$$\frac{\mathfrak{B}(\Xi_b^- \to p\pi^-\pi^-)}{\mathfrak{B}(\Xi_b^- \to pK^-K^-)} < 0.56\ (0.63)$$

$$R_{\Omega_b^- \to pK^-K^-} < 18\ (22) \times 10^{-5}$$

$$R_{\Omega_b^- \to pK^-\pi^-} < 51\ (62) \times 10^{-5}$$

$$R_{\Omega_b^- \to p\pi^-\pi^-} < 109\ (124) \times 10^{-5}$$

Upper limits at 90 (95) % confidence level

Where $R_{\Xi_b^-(\Omega_b^-) \to ph^-h'^-} = \frac{f_{\Xi_b^-(\Omega_b^-)}}{f_u} \times \frac{\mathfrak{B}(\Xi_b^-(\Omega_b^-) \to p\, h^- h'^-)}{\mathfrak{B}(B^- \to K^+ K^- K^-)}$

# Resonance contributions in $\Xi_b^- \to pK^-K^-$

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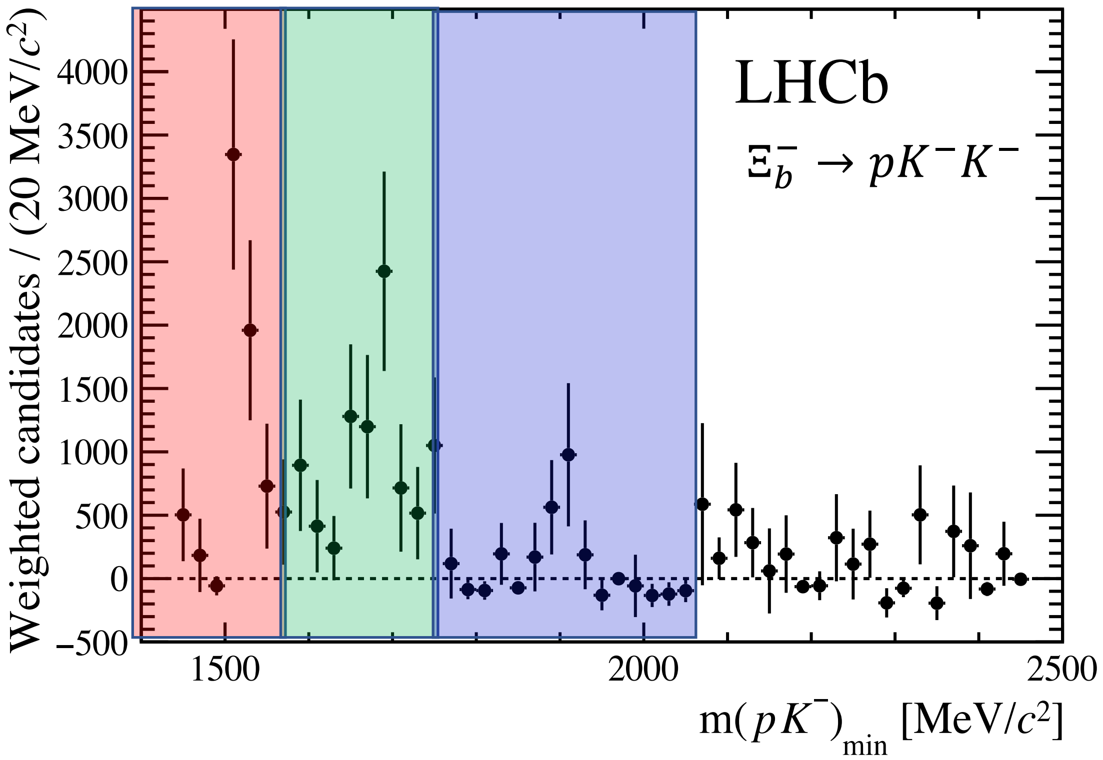


- Possible contributions from $\Lambda(1405)[J^P = \frac{1}{2}^-]$ and $\Lambda(1520)\ [\frac{3}{2}^-]$.
- Possible contributions from $\Lambda(1670)[\frac{1}{2}^-]$, $\Lambda(1690)[\frac{3}{2}^-]$ and other broad states.
- Possible contribution from $\Lambda(1830)[\frac{5}{2}^-]$, $\Lambda(1890)[\frac{3}{2}^+]$ and other broad states.

# Conclusion

- At LHCb, we now not only observe charmless decay of $\Lambda_b^0$ baryon but also charmless decays of $\Xi_b^-$ baryon.
- No observation of charmless decays of $\Omega_b^-$ baryons yet.
- Adding Run II data, good prospects to probe the dynamics of charmless $\Xi_b^-$ decays and to conduct CPV searches.
- With the LHCb upgrade detailed studies of these decay modes will become possible.
- Theoretical predictions for CPV in b-baryon decays are needed to confront the increasingly precise measurements.

# Backup

# $m(K^-p)$ distribution from $\Lambda_b^0 \to J/\psi p K^-$

Phys. Rev. Lett. 115 (2015) 072001