

Measurement of branching fractions and CP asymmetries in $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0 h^-$ decays

[[JHEP 10 \(2025\) 169](#)]

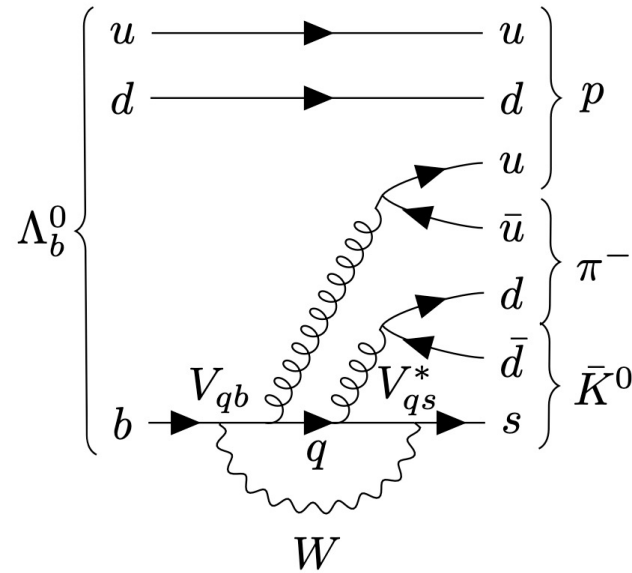
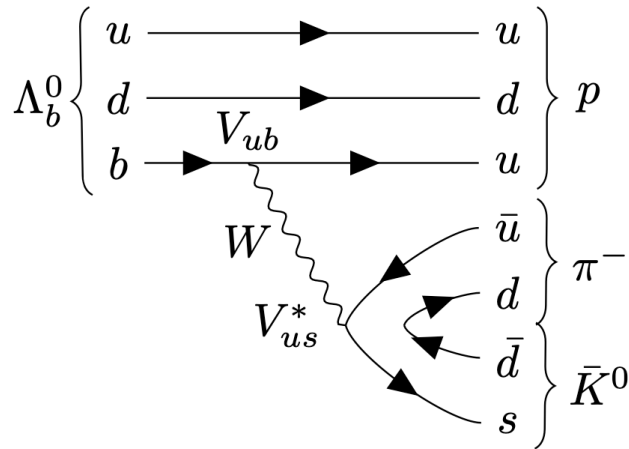
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On behalf of the LHCb Collaboration

CLHCP 2025

Motivation

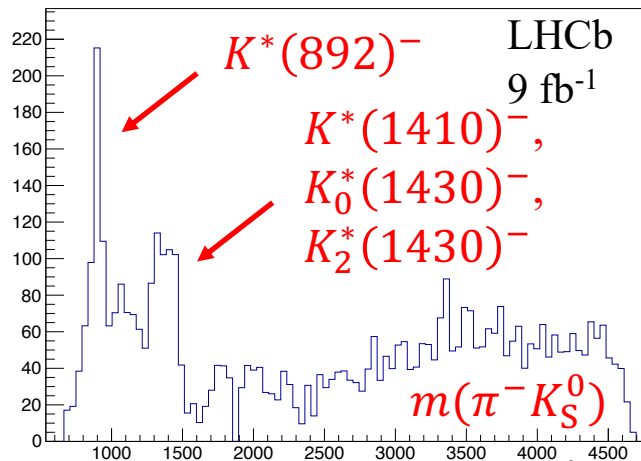
- In the charmless $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0 h^-$ ($h = K, \pi$) decays
 - Contribution from tree and penguin diagrams
 - Example: leading order Feynman diagrams for $\Lambda_b^0 \rightarrow pK_S^0 \pi^-$



- Possible A^{CP} due to interference between tree and penguin diagrams in the charmless $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0 h^-$ ($h = K, \pi$) decays

Motivation

- A^{CP} in the $\Lambda_b^0 \rightarrow pK^*(892)^-$ decay is predicted to be
 - About 20%:
 - $(19.7 \pm 1.4)\%$ (GFA)
[\[Phys. Rev. D 91 \(2015\) 116007\]](#),
[Phys. Rev. D 95 \(2017\) 093001\]](#)
 - $(31.1 \pm 2.8)\%$ (QCDF)
[\[Phys. Rev. D 99 \(2019\) 054020\]](#)
 - $(19.3 \pm 0.8)\%$ (LFQM)
[\[Phys. Lett. B 815 \(2021\) 136125\]](#)
 - Consistent with 0:
 - $(-5_{-16}^{+10})\%$ (PQCD)
[\[Phys. Rev. Lett. 134 \(2025\) 221801\]](#)
 - $(2 \pm 4)\%$ (Final-state rescattering)
[\[arXiv:2412.20458\]](#)
 - Indicate a significant cancellation of A^{CP} among the partial waves
- In the charmless $\Lambda_b^0 \rightarrow pK_S^0\pi^-$ decay, there is a significant contribution from the intermediate $\Lambda_b^0 \rightarrow pK^*(892)^-(\rightarrow \pi^-K_S^0)$ decay
 - Sweighted $\Lambda_b^0 \rightarrow pK_S^0\pi^-$ data (Run1+Run2, K_S^0 DD+LL)



- Provide a test for QCD approaches mentioned above

Strategy (BF)

- Signal channels:
 - Charmless $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0 h^-$ ($h = K, \pi$)
- Control channel:
 - $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK_S^0)\pi^-$

- Relative branching fraction

$$\mathcal{R}(\Lambda_b^0 \rightarrow pK_S^0 h^-) \equiv \frac{\mathcal{B}(\Lambda_b^0 \rightarrow pK_S^0 h^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) \mathcal{B}(\Lambda_c^+ \rightarrow pK_S^0)} = \frac{N(\Lambda_b^0 \rightarrow pK_S^0 h^-)/\epsilon(\Lambda_b^0 \rightarrow pK_S^0 h^-)}{N(\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK_S^0)\pi^-)/\epsilon(\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK_S^0)\pi^-)}$$

yield of signal channel efficiency of signal channel b -quark fragmentation fraction
↓ ↓ ↓

$$\mathcal{R}(\Xi_b^0 \rightarrow pK_S^0 h^-) \equiv \frac{\mathcal{B}(\Xi_b^0 \rightarrow pK_S^0 h^-)}{\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) \mathcal{B}(\Lambda_c^+ \rightarrow pK_S^0)} = \frac{N(\Xi_b^0 \rightarrow pK_S^0 h^-)/\epsilon(\Xi_b^0 \rightarrow pK_S^0 h^-)}{N(\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK_S^0)\pi^-)/\epsilon(\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK_S^0)\pi^-)} \times \frac{f_{\Lambda_b^0}}{f_{\Xi_b^0}}$$

↑ ↑ ↓
yield of control channel efficiency of control channel

- External input for absolute branching fraction

- $\mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) \mathcal{B}(\Lambda_c^+ \rightarrow pK_S^0) = (7.79 \pm 0.72) \times 10^{-5}$ [\[PDG\]](#)
- $[\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}]_{\text{Run1}} = (6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2}$ [\[Phys. Rev. D99 \(2019\) 052006\]](#)
- $[\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}]_{\text{Run2}} = (8.2 \pm 0.7 \pm 0.6 \pm 2.4) \times 10^{-2}$

Strategy (A^{CP})

- Signal channels:
 - Charmless $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0 h^-$ ($h = K, \pi$)
- Control channel:
 - $\Lambda_b^0 \rightarrow \Lambda_c^+(\rightarrow pK_S^0)\pi^-$
 - $A^{CP} = 0$
- A^{CP} in the signal channel

$$A^{CP}(\text{signal}) = A^{\text{raw}}(\text{signal}) - A^{\text{P}}(\text{signal}) - A^{\text{D}}(\text{signal}) - A^{\text{trigger}}(\text{signal}) - A^{\text{PID}}(\text{signal})$$

$\uparrow$
 $\frac{N(\Lambda_b^0) - N(\bar{\Lambda}_b^0)}{N(\Lambda_b^0) + N(\bar{\Lambda}_b^0)}$

$\uparrow$
 $\Lambda_b^0(\Xi_b^0)$ production
asymmetry

$\uparrow$
 ph^- detection
asymmetry

$\uparrow$
 L0(HLT1) trigger
asymmetry

$\uparrow$
 PID
asymmetry

- The control channel is used to cancel most of nuisance asymmetries

$$A^{CP}(\text{signal}) = \Delta A^{\text{raw}} - \Delta A^{\text{P}} - \Delta A^{\text{D}} - \Delta A^{\text{trigger}} - \Delta A^{\text{PID}}$$
 - $\Delta A^{\text{X}} = A^{\text{X}}(\text{signal}) - A^{\text{X}}(\text{control})$
 - Residual nuisance asymmetries are estimated by corresponding asymmetry tables

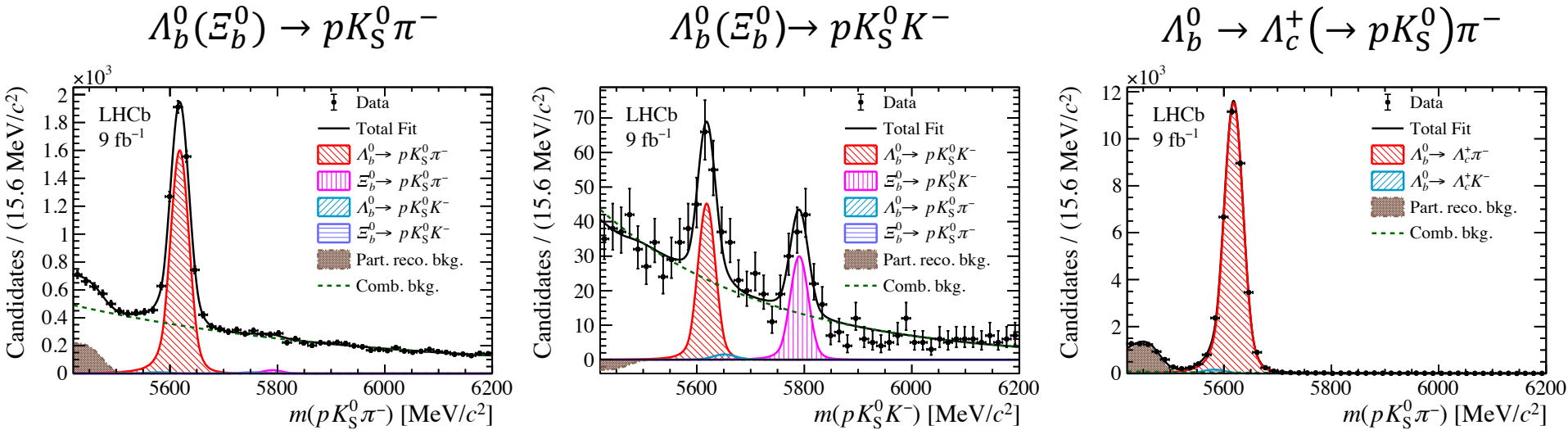
Mass fit results

- Using Run1+Run2 LHCb data (9fb⁻¹)
- Selections
 - Peaking backgrounds removed by veto or PID cut
 - BDT classifiers trained on kinematic, topological, PID variables
- Mass fit plots (Run1+Run2, K_S^0 DD+LL)

Signal yield

Decay	Yield	Significance
$\Lambda_b^0 \rightarrow p K_S^0 \pi^-$	$4\,740 \pm 90$	—
$\Lambda_b^0 \rightarrow p K_S^0 K^-$	127 ± 17	$8.1\,\sigma$
$\Xi_b^0 \rightarrow p K_S^0 \pi^-$	70 ± 40	$1.0\,\sigma$
$\Xi_b^0 \rightarrow p K_S^0 K^-$	88 ± 13	$8.0\,\sigma$
$\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K_S^0) \pi^-$	$34\,680 \pm 200$	—

- Observation of $\Lambda_b^0 \rightarrow p K_S^0 K^-$ and $\Xi_b^0 \rightarrow p K_S^0 K^-$ decays



Measurement of branching fractions

- Efficiency is estimated using simulation
 - Corrections are applied to account for known discrepancies between MC/data
- Branching fraction

$$\mathcal{B}(\Lambda_b^0 \rightarrow p K_S^0 h^-) = \frac{N(\Lambda_b^0 \rightarrow p K_S^0 h^-)/\epsilon(\Lambda_b^0 \rightarrow p K_S^0 h^-)}{N(\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K_S^0) \pi^-)/\epsilon(\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K_S^0) \pi^-)} \times \mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) \mathcal{B}(\Lambda_c^+ \rightarrow p K_S^0)$$

$$\mathcal{B}(\Xi_b^0 \rightarrow p K_S^0 h^-) = \frac{N(\Xi_b^0 \rightarrow p K_S^0 h^-)/\epsilon(\Xi_b^0 \rightarrow p K_S^0 h^-)}{N(\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K_S^0) \pi^-)/\epsilon(\Lambda_b^0 \rightarrow \Lambda_c^+ (\rightarrow p K_S^0) \pi^-)} \times \mathcal{B}(\Lambda_b^0 \rightarrow \Lambda_c^+ \pi^-) \mathcal{B}(\Lambda_c^+ \rightarrow p K_S^0) / \frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}$$

- Results

	Result [$\times 10^{-6}$]
$\mathcal{B}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-)$	10.62 ± 0.21 (stat) ± 0.16 (syst) ± 0.98 (norm)
$\mathcal{B}(\Lambda_b^0 \rightarrow p K_S^0 K^-)$	0.61 ± 0.08 (stat) ± 0.06 (syst) ± 0.06 (norm)
$\mathcal{B}(\Xi_b^0 \rightarrow p K_S^0 \pi^-)$	< 2.8 (3.2) at 90 (95)% CL
$\mathcal{B}(\Xi_b^0 \rightarrow p K_S^0 K^-)$	3.9 ± 0.6 (stat) ± 0.5 (syst) ± 0.4 (norm) ± 1.4 ($f_{\Xi_b^0}/f_{\Lambda_b^0}$)

- Consistent with LHCb measurement of $\mathcal{B}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-)$ using 2011 data

$$\mathcal{B}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-) = [12.6 \pm 1.9 \text{ (stat)} \pm 0.9 \text{ (syst)} \pm 3.4 (f_{\Lambda_b^0}/f_d) \pm 0.5 \text{ (norm)}] \times 10^{-6}$$

[JHEP 04 (2014) 087]

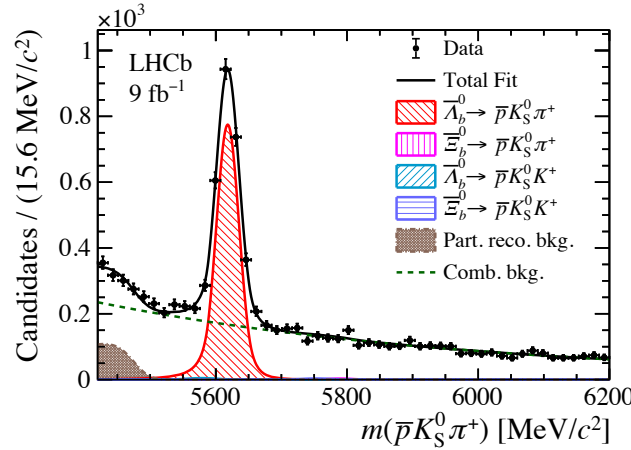
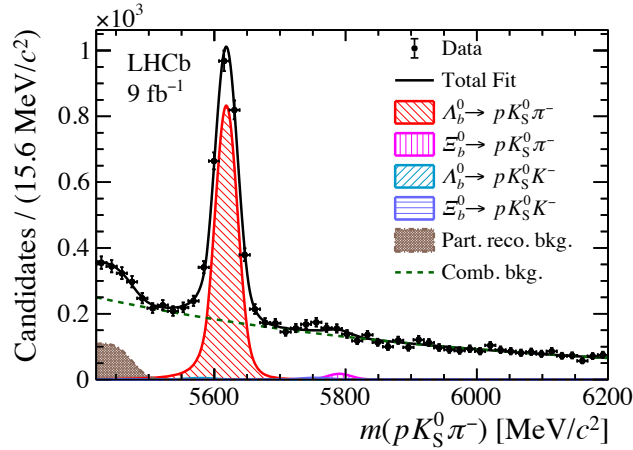
Systematic uncertainty (BF)

- Sources of systematic uncertainty
 - Efficiency estimation
 - the limited size of simulation samples
 - PID correction
 - **phase space correction**
 - Difference in Ξ_b^0 kinematic between MC/data for Ξ_b^0 decays
 - Mass fit model
 - Constraint on the MisID yield
 - Potential partially reconstructed background from Ξ_b^0 decays in the $pK_S^0 K^-$ mass spectra
- Relative systematic uncertainties [%]

	Efficiency	Ξ_b^0 kinematics	Model	MisID bkg.	Ξ_b^0 bkg.	Total
$\mathcal{R}(\Lambda_b^0 \rightarrow pK_S^0 \pi^-)$	1.4	—	0.3	0.1	—	1.5
$\mathcal{R}(\Lambda_b^0 \rightarrow pK_S^0 K^-)$	6.4	—	3.6	1.3	5.7	9.3
$\mathcal{R}(\Xi_b^0 \rightarrow pK_S^0 \pi^-) \times \frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}$	35.8	15.8	1.7	5.6	—	39.5
$\mathcal{R}(\Xi_b^0 \rightarrow pK_S^0 K^-) \times \frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}$	9.1	5.9	4.8	1.0	4.6	12.7

A^{CP} results

- $A^{CP}(\text{signal}) = \Delta A^{\text{raw}} - \Delta A^{\text{P}} - \Delta A^{\text{D}} - \Delta A^{\text{trigger}} - \Delta A^{\text{PID}}$
- $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0\pi^-$ decay (Run1+Run2, K_S^0 DD+LL)



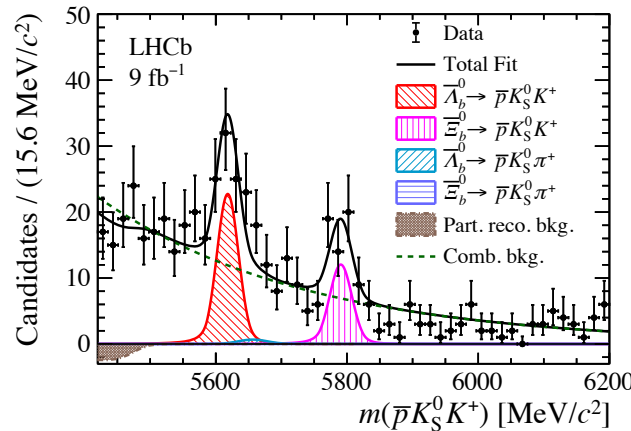
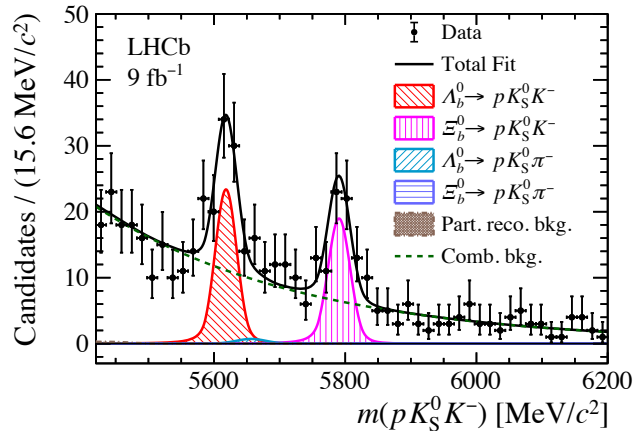
$\mathcal{A}^{\text{raw}}(\Lambda_b^0 \rightarrow pK_S^0\pi^-)$ [%]
3.59 ± 1.84 (stat)
$\mathcal{A}^{CP}(\Lambda_b^0 \rightarrow pK_S^0\pi^-)$ [%]
3.41 ± 1.93 (stat) ± 0.93 (syst)

consistent with 2011 result

[\[JHEP 04 \(2014\) 087\]](#)

Run1 Result (2011 data) [%]
22 ± 13 (stat) ± 3 (syst)

- $\Lambda_b^0(\Xi_b^0) \rightarrow pK_S^0K^-$ decay (Run1+Run2, K_S^0 DD+LL)



$\mathcal{A}^{\text{raw}}(\Lambda_b^0 \rightarrow pK_S^0K^-)$ [%]
1.63 ± 12.88 (stat)
$\mathcal{A}^{CP}(\Lambda_b^0 \rightarrow pK_S^0K^-)$ [%]
2.37 ± 12.89 (stat) ± 9.04 (syst)

$\mathcal{A}^{\text{raw}}(\Xi_b^0 \rightarrow pK_S^0K^-)$ [%]
22.56 ± 14.91 (stat)
$\mathcal{A}^{CP}(\Xi_b^0 \rightarrow pK_S^0K^-)$ [%]
22.43 ± 14.92 (stat) ± 11.32 (syst)

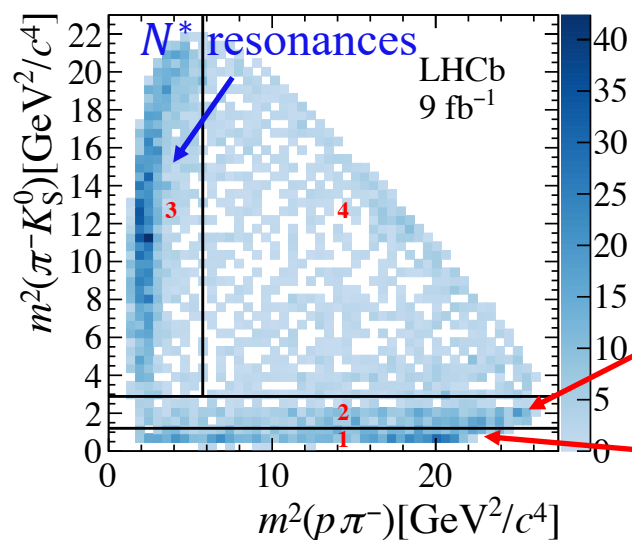
Systematic uncertainty (A^{CP})

- Sources of systematic uncertainty
 - Mass fit model
 - Constraint on the MisID yield
 - Potential partially reconstructed background from Ξ_b^0 decays in the $pK_S^0 K^-$ mass spectra
 - Fit validation
 - Ξ_b^0 production asymmetry
 - PID asymmetry
 - Estimation of residual nuisance asymmetries
- Systematic uncertainties [%]

	$\mathcal{A}^{CP}(\Lambda_b^0 \rightarrow pK_S^0 \pi^-)$	$\mathcal{A}^{CP}(\Lambda_b^0 \rightarrow pK_S^0 K^-)$	$\mathcal{A}^{CP}(\Xi_b^0 \rightarrow pK_S^0 K^-)$
Model	< 0.1	0.4	1.0
MisID bkg.	< 0.1	0.2	1.2
Ξ_b^0 bkg.	–	7.5	5.6
Fit bias	0.1	–	–
$\mathcal{A}^P(\Xi_b^0)$	–	–	6.3
$\mathcal{A}^{PID}$	0.6	4.8	7.4
Residual asym.	0.7	1.6	0.6
Total	0.9	9.0	11.3

Local A^{CP} for the $\Lambda_b^0 \rightarrow p K_S^0 \pi^-$ decay

- Only $\Lambda_b^0 \rightarrow p K_S^0 \pi^-$ (yield ~ 4740) is considered for local A^{CP} measurement
- Resonances (sweighted data, Run1+Run2, K_S^0 DD+LL)



Bin 1: $K^*(892)^-$ region

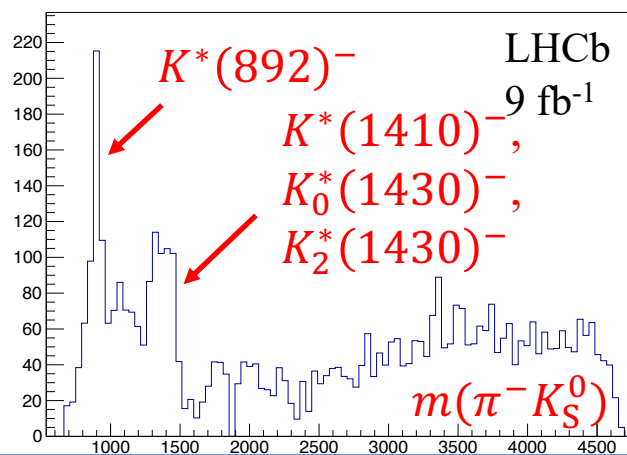
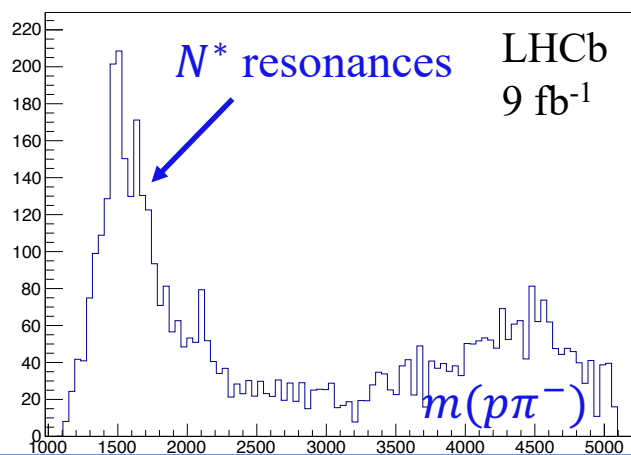
Bin 2: $K^*(1410)^-$, $K_0^*(1430)^-$, $K_2^*(1430)^-$ region

Bin 3: N^* region

Bin 4: region free of resonances

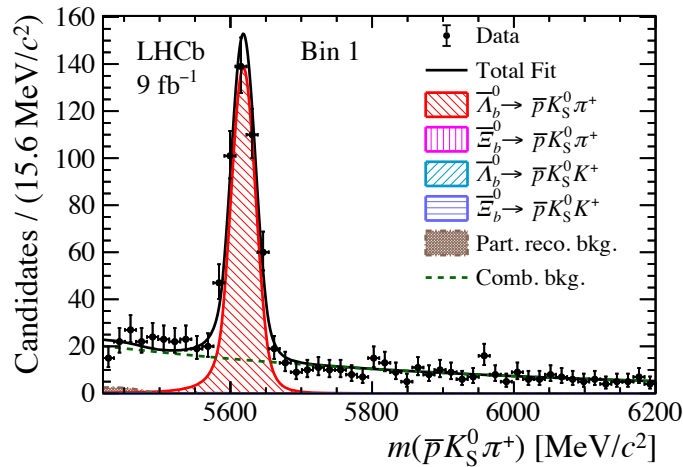
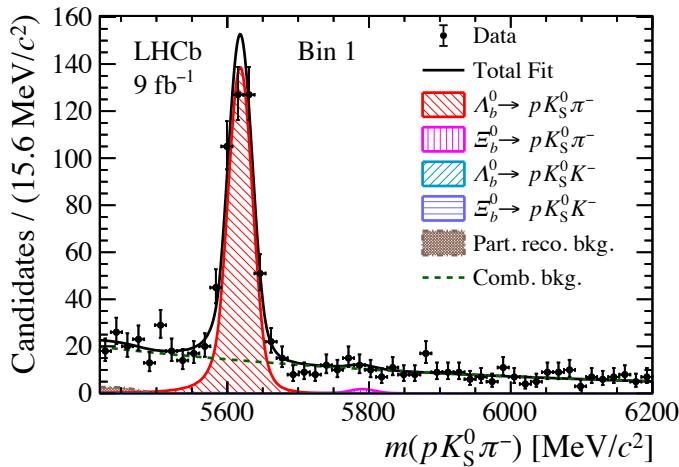
$K^*(1410)^-$, $K_0^*(1430)^-$, $K_2^*(1430)^-$

$K^*(892)^-$



A^{CP} results

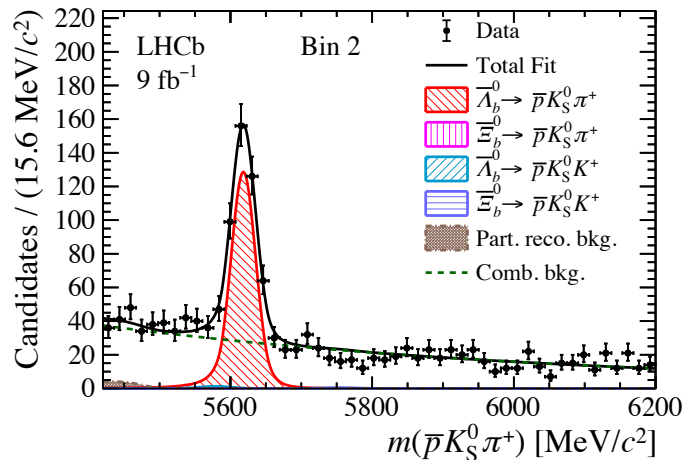
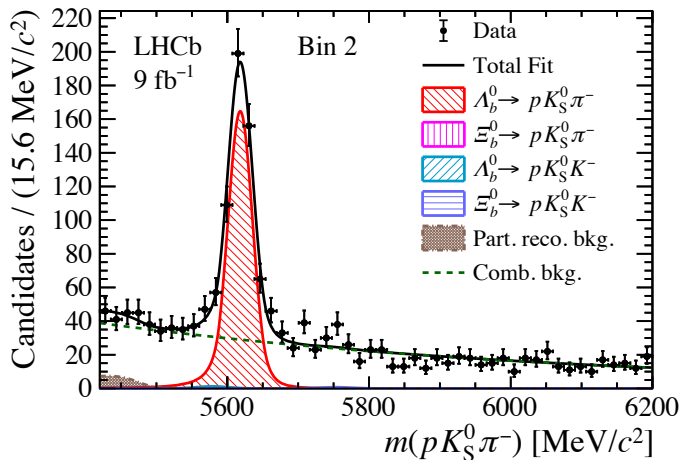
- $K^*(892)^-$ region (Run1+Run2, K_S^0 DD+LL)



$\mathcal{A}_1^{\text{raw}}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-) [\%]$
$0.01 \pm 4.00 \text{ (stat)}$
$\mathcal{A}_1^{CP}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-) [\%]$
$-0.55 \pm 4.03 \text{ (stat)} \pm 1.91 \text{ (syst)}$

significantly smaller than
the theoretical prediction
(~20%)

- $K^*(1410)^-, K_0^*(1430)^-, K_2^*(1430)^-$ region (Run1+Run2, K_S^0 DD+LL)

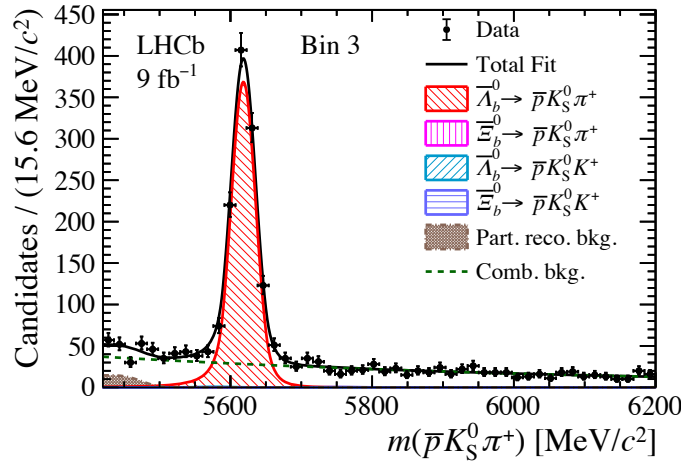
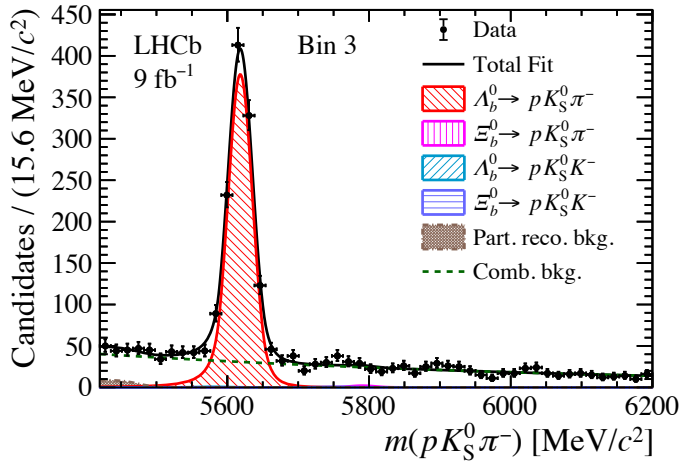


$\mathcal{A}_2^{\text{raw}}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-) [\%]$
$12.27 \pm 4.13 \text{ (stat)}$
$\mathcal{A}_2^{CP}(\Lambda_b^0 \rightarrow p K_S^0 \pi^-) [\%]$
$12.40 \pm 4.16 \text{ (stat)} \pm 1.84 \text{ (syst)}$

2.7σ

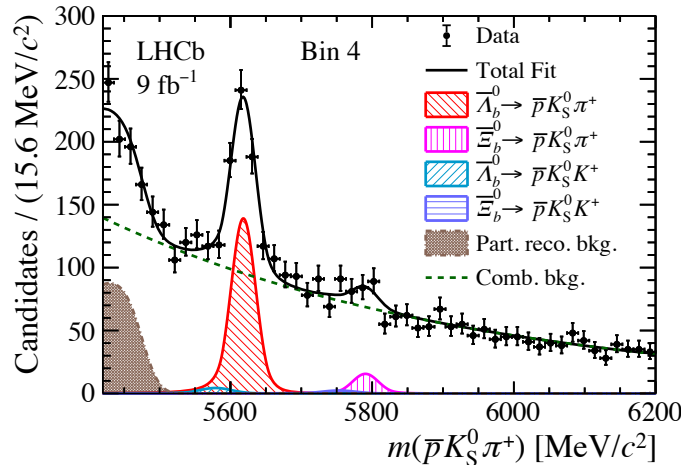
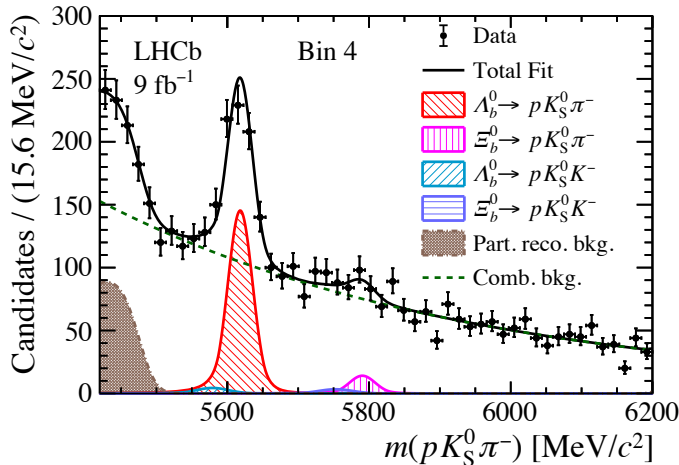
A^{CP} results

- N^* region (Run1+Run2, K_S^0 DD+LL)



$\mathcal{A}_3^{\text{raw}}(\Lambda_b^0 \rightarrow pK_S^0\pi^-)$ [%]
1.20 ± 2.37 (stat)
$\mathcal{A}_3^{CP}(\Lambda_b^0 \rightarrow pK_S^0\pi^-)$ [%]
0.55 ± 2.44 (stat) ± 1.11 (syst)

- Non-resonant region (Run1+Run2, K_S^0 DD+LL)



$\mathcal{A}_4^{\text{raw}}(\Lambda_b^0 \rightarrow pK_S^0\pi^-)$ [%]
2.19 ± 5.43 (stat)
$\mathcal{A}_4^{CP}(\Lambda_b^0 \rightarrow pK_S^0\pi^-)$ [%]
3.29 ± 5.46 (stat) ± 2.02 (syst)

Summary

- Branching fractions of $\Lambda_b^0 \rightarrow pK_S^0 h^-$ and $\Xi_b^0 \rightarrow pK_S^0 K^-$ decays are measured
- Integrated A^{CP} in charmless $\Lambda_b^0 \rightarrow pK_S^0 h^-$ and $\Xi_b^0 \rightarrow pK_S^0 K^-$ decays are measured
 - Consistent with Run1 result of $A^{CP}(\Lambda_b^0 \rightarrow pK_S^0 \pi^-)$, with the precision improved by a factor of 6.5
 - No evidence of global CPV
- Local A^{CP} for $\Lambda_b^0 \rightarrow pK_S^0 \pi^-$ decay are measured
 - A^{CP} in the $K^*(892)^-$ dominant bin is $(-0.6 \pm 4.0(\text{stat}) \pm 1.9(\text{syst}))\%$, significantly smaller than the predicted value of 20%
 - No evidence of local CPV in $\Lambda_b^0 \rightarrow pK_S^0 \pi^-$ decay

backup