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

[arXiv:2508.17836]

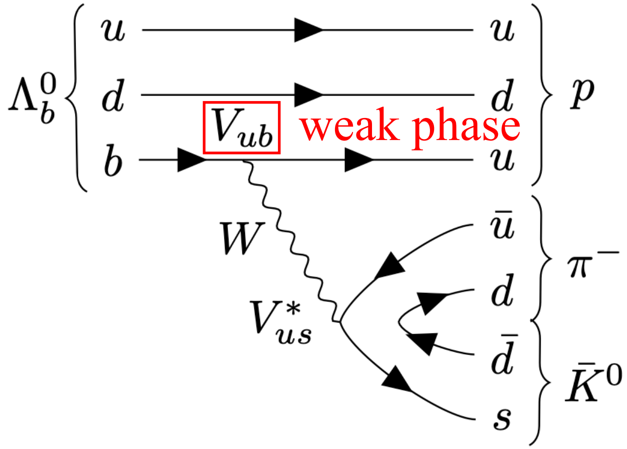
Z. Chen[1], F. Ferrari[2], T. Gershon[3], T. Latham[3], V. Macko[4], D.P O'Hanlon[2], S. Perazzini[5], W. Qian[1], N. Serra[6], R. Silva Coutinho[7], V. Vagnoni[2], D. Xiao[8], Y. Xie[8], Y. Zhang[9], Y. Zheng[1]

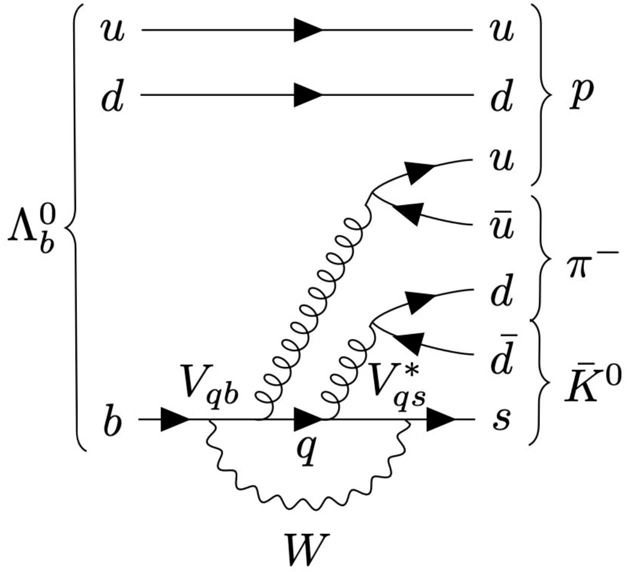
[1] *University of Chinese Academy of Sciences*
[2] *INFN Sezione di Bologna*
[3] *Department of Physics, University of Warwick*
[4] *Institute of Physics, Ecole Polytechnique Federale de Lausanne*
[5] *European Organization for Nuclear Research*
[6] *Physik-Institut, Universität Zürich*
[7] *Physics Department, Syracuse University*
[8] *Institute of Particle Physics, Central China Normal University*
[9] *Peking University*

CLHCP 2025

Motivation

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

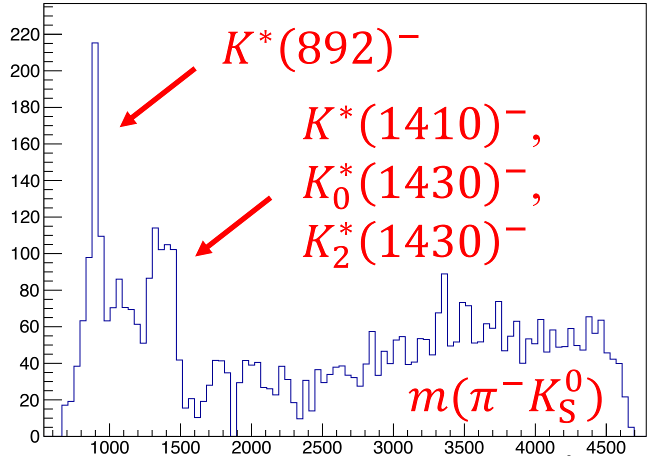




- Possible A^{CP} due to interference between tree and penguin diagrams in the charmless $\Lambda_b^0(\Xi_b^0) \to p K_S^0 h^-$ $(h = K, \pi)$ decays

Motivation

- A^{CP} in the $\Lambda_b^0 \to pK^*(892)^-$ 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:
    - $(-5^{+10}_{-16})\%$ (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 $\Lambda_b^0 \to pK_S^0\pi^-$ decay, there is a significant contribution from the intermediate $\Lambda_b^0 \to pK^*(892)^-(\to \pi^-K_S^0)$ decay
  - Sweighted $\Lambda_b^0 \to pK_S^0\pi^-$ data (Run1+Run2, K_S^0 DD+LL)



- Provide a test for QCD approaches mentioned above

Strategy (BF)

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

yield of signal channel

efficiency of signal channel

b-quark fragmentation fraction

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

yield of control channel

efficiency of control channel

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

- External input for absolute branching fraction
  - $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)\mathcal{B}(\Lambda_c^+ \to pK_S^0) = (7.79 \pm 0.72) \times 10^{-5}$ [PDG]
  - $[\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}]_{\rm Run1} = (6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2}$ [Phys. Rev. D99 (2019) 052006]

    $[\frac{f_{\Xi_b^0}}{f_{\Lambda_b^0}}]_{\rm Run2} = (8.2 \pm 0.7 \pm 0.6 \pm 2.4) \times 10^{-2}$

Strategy (A^{CP})

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

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

$\frac{N(\Lambda_b^0) - N(\bar{\Lambda}_b^0)}{N(\Lambda_b^0) + N(\bar{\Lambda}_b^0)}$ | $\Lambda_b^0(\Xi_b^0)$ production asymmetry | ph^- detection asymmetry | L0(HLT1) trigger asymmetry | 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

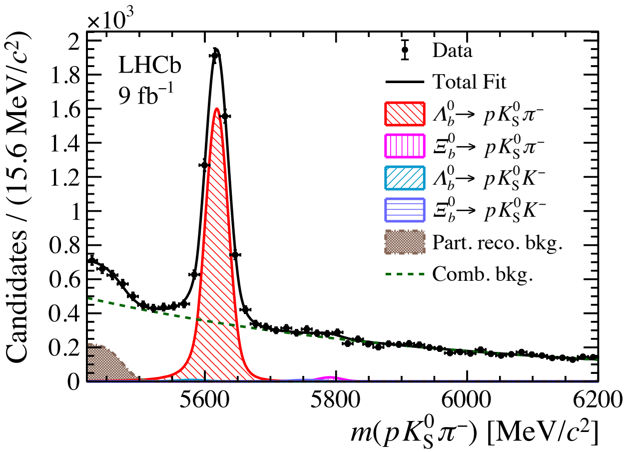
- Using Run1+Run2 data (9fb^{-1})
- Selections
  - Peaking backgrounds removed by veto or PID cut
  - BDT classifiers trained on kinematic, topological, PID variables
- Mass fit plots (Run1+Run2, K_S^0 DD+LL)

- Signal yield

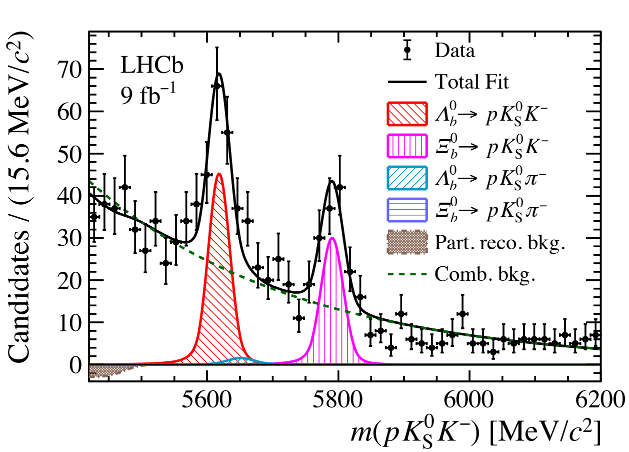
Decay	Yield	Significance
$\Lambda_b^0 \to pK_S^0\pi^-$	$4\,740 \pm 90$	–
$\Lambda_b^0 \to pK_S^0K^-$	127 ± 17	$8.1\,\sigma$
$\Xi_b^0 \to pK_S^0\pi^-$	70 ± 40	$1.0\,\sigma$
$\Xi_b^0 \to pK_S^0K^-$	88 ± 13	$8.0\,\sigma$
$\Lambda_b^0 \to \Lambda_c^+(\to pK_S^0)\pi^-$	$34\,680 \pm 200$	–

- Observation of $\Lambda_b^0 \to pK_S^0K^-$ and $\Xi_b^0 \to pK_S^0K^-$ decays

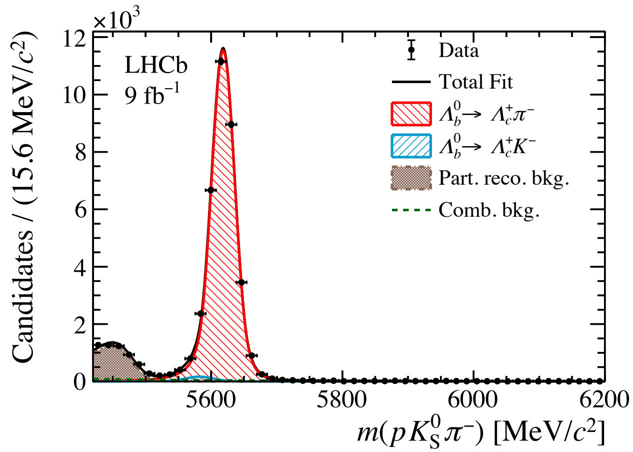
$\Lambda_b^0(\Xi_b^0) \to pK_S^0\pi^-$



$\Lambda_b^0(\Xi_b^0) \to pK_S^0K^-$



$\Lambda_b^0 \to \Lambda_c^+(\to pK_S^0)\pi^-$



Measurement of branching fractions

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

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

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

- Results

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

- Consistent with LHCb measurement of $B(\Lambda_b^0 \to pK_S^0\pi^-)$ using 2011 data

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

[JHEP 04 (2014) 087]

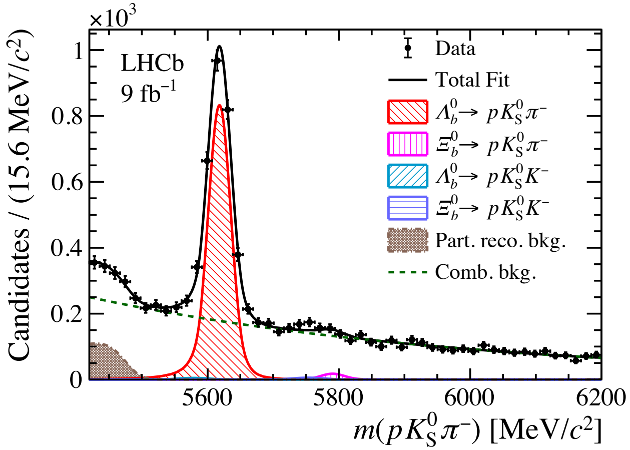
Systematic uncertainty (BF)

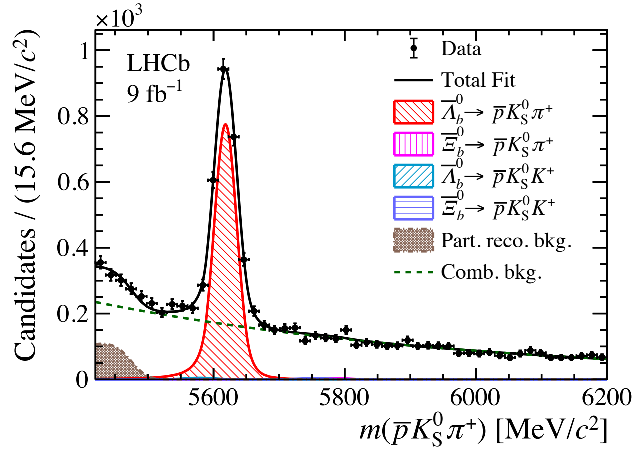
- Sources of systematic uncertainty
  - Efficiency estimation
    - the limited size of simulation samples
    - PID correction
    - phase space correction
  - Difference in Ξ_b^0 kinematic between MC/data for Ξ_b^0 decays
  - Mass fit model
  - Constraint on the MisID yield
  - Potential partially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

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

A^{CP} results

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





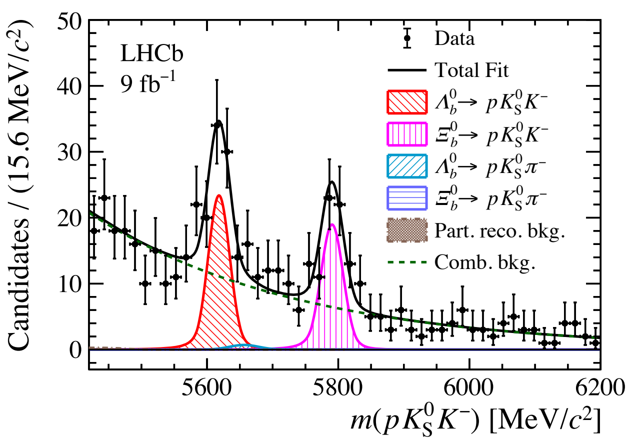
$\mathcal{A}^{\text{raw}}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
$3.59 \pm 1.84\,(\text{stat})$
$\mathcal{A}^{CP}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
$3.41 \pm 1.93\,(\text{stat}) \pm 0.93\,(\text{syst})$

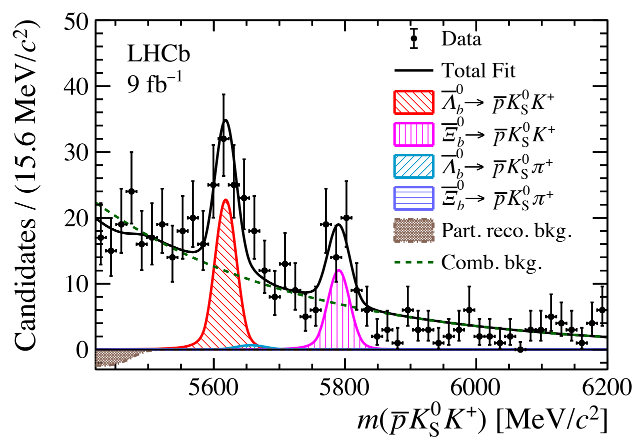
consistent with 2011 result

[JHEP 04 (2014) 087]

Run1 Result (2011 data) [%]
$22 \pm 13\,(\text{stat}) \pm 3\,(\text{syst})$

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





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

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

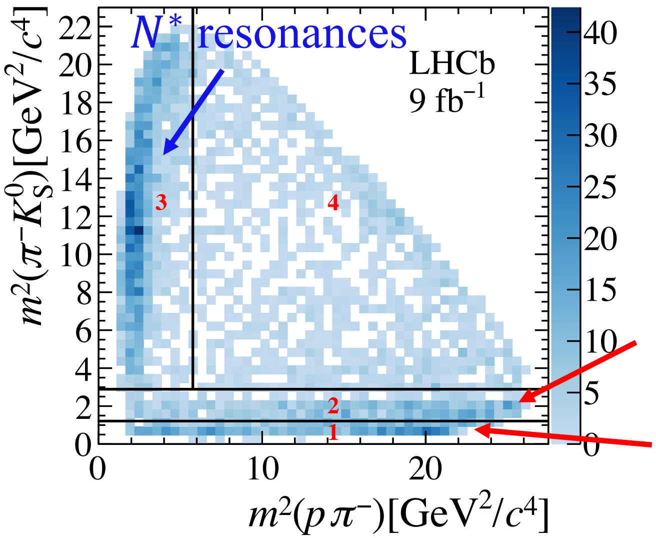
Systematic uncertainty (A^{CP})

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

	$\mathcal{A}^{CP}(\Lambda_b^0 \to pK_S^0\pi^-)$	$\mathcal{A}^{CP}(\Lambda_b^0 \to pK_S^0K^-)$	$\mathcal{A}^{CP}(\Xi_b^0 \to pK_S^0K^-)$
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 $\Lambda_b^0 \to pK_S^0\pi^-$ decay

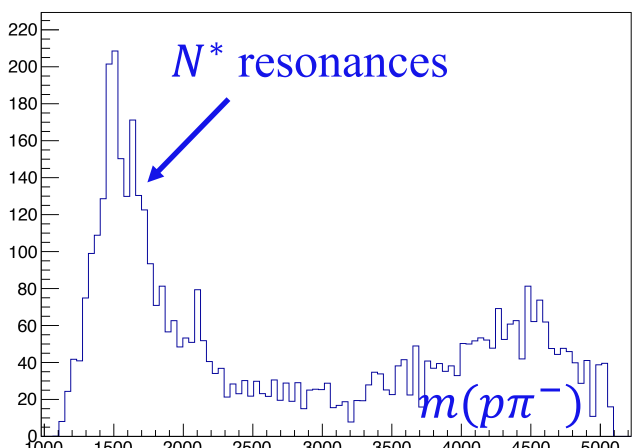
- Only $\Lambda_b^0 \to pK_S^0\pi^-$ (yield ~ 4740) is considered for local A^{CP} measurement
- Resonances (sweighted data, Run1+Run2, K_S^0 DD+LL)

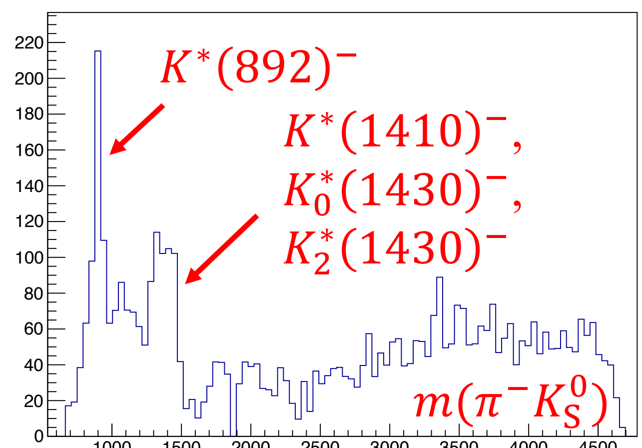


Bin 1: $K^*(892)^-$ region
Bin 2: $K^*(1410)^-$, $K_0^*(1430)^-$, $K_2^*(1430)^-$ region
Bin 3: N^* region
Bin 4: region free of resonances

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

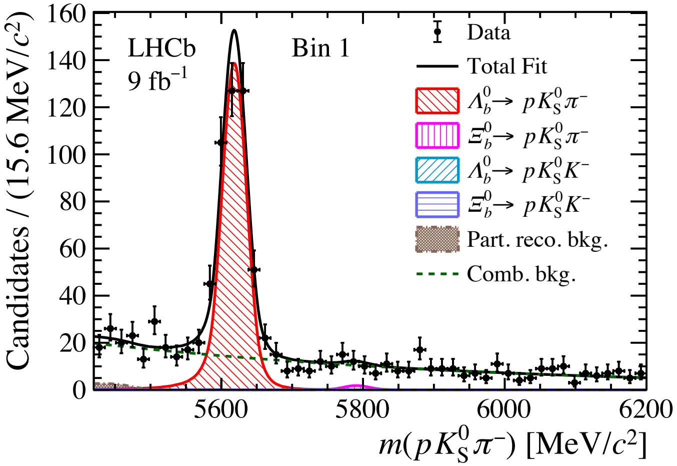
$K^*(892)^-$

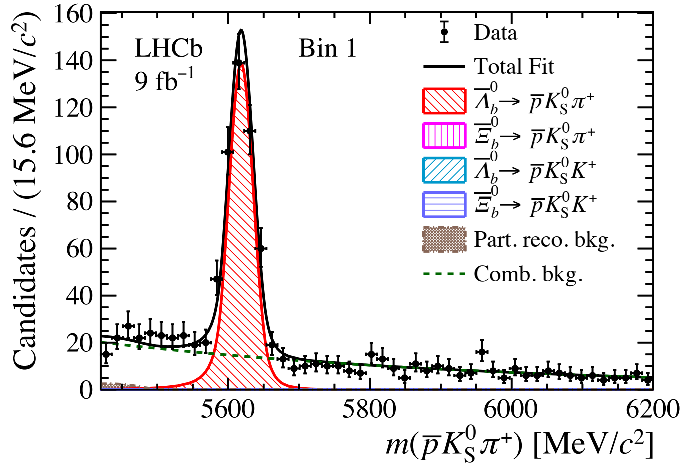




A^{CP} results

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

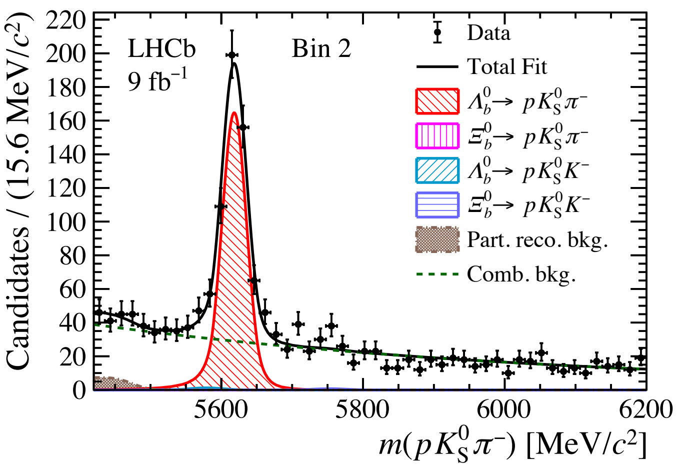


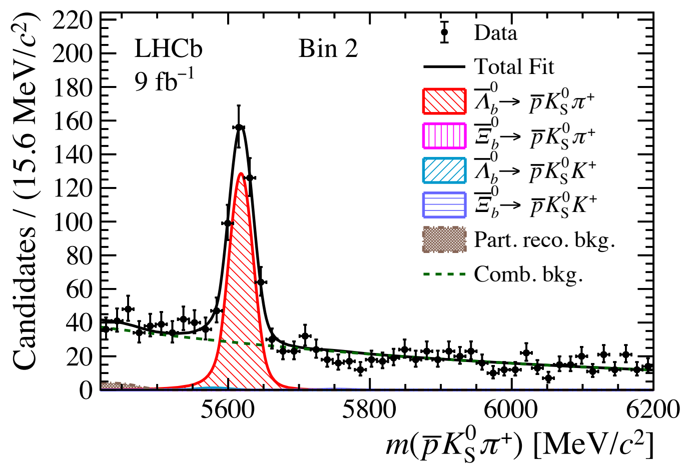


$\mathcal{A}_1^{\text{raw}}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
$0.01 \pm 4.00\,(\text{stat})$
$\mathcal{A}_1^{CP}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
$-0.55 \pm 4.03\,(\text{stat}) \pm 1.91\,(\text{syst})$

significantly smaller than the theoretical prediction (~20%)

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



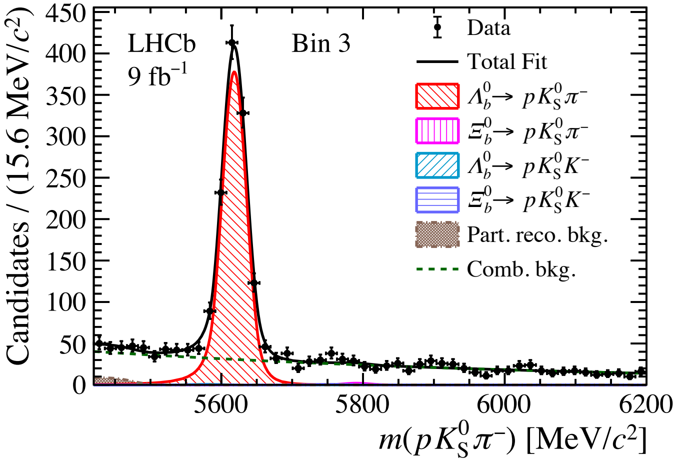


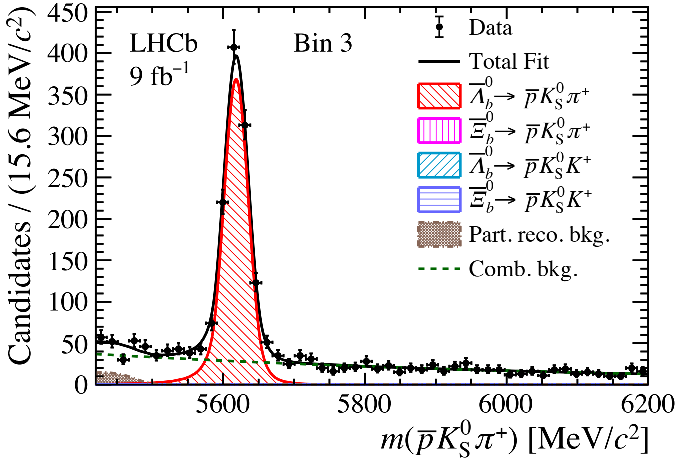
$\mathcal{A}_2^{\text{raw}}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
$12.27 \pm 4.13\,(\text{stat})$
$\mathcal{A}_2^{CP}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
$12.40 \pm 4.16\,(\text{stat}) \pm 1.84\,(\text{syst})$

2.7σ

A^{CP} results

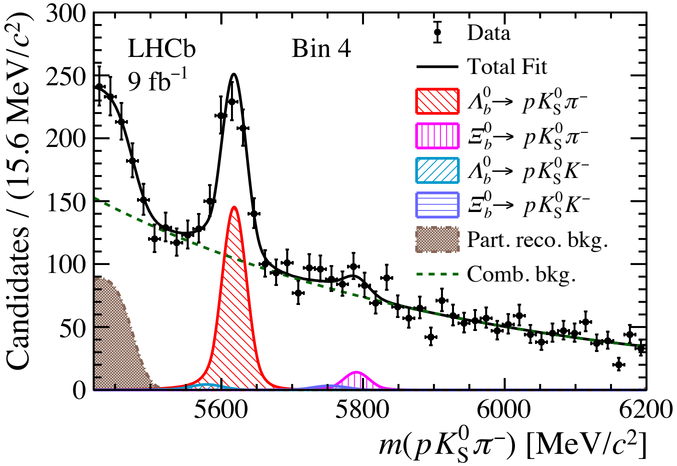
- N^* region (Run1+Run2, K_S^0 DD+LL)

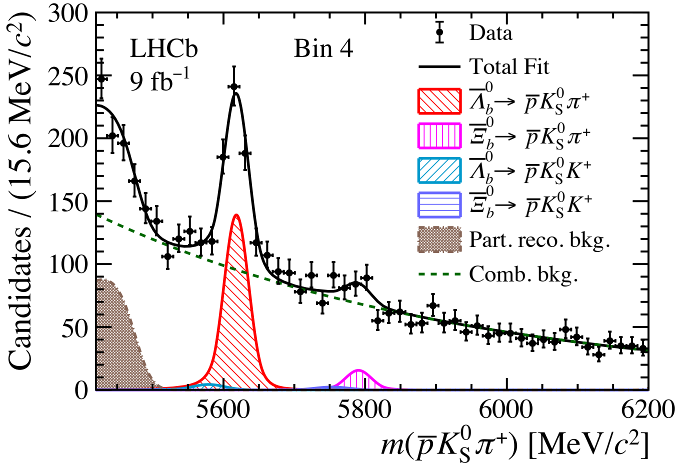




$\mathcal{A}_3^{\mathrm{raw}}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
1.20 ± 2.37 (stat)
$\mathcal{A}_3^{CP}(\Lambda_b^0 \to pK_S^0\pi^-)$ [%]
0.55 ± 2.44 (stat) ± 1.11 (syst)

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





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

Summary

- Branching fractions of $\Lambda_b^0 \to pK_S^0h^-$ and $\Xi_b^0 \to pK_S^0K^-$ decays are measured
- Integrated A^{CP} in charmless $\Lambda_b^0 \to pK_S^0h^-$ and $\Xi_b^0 \to pK_S^0K^-$ decays are measured
  - Consistent with Run1 result of $A^{CP}(\Lambda_b^0 \to pK_S^0\pi^-)$, with the precision improved by a factor of 6.5
  - No evidence of global CPV
- Local A^{CP} for $\Lambda_b^0 \to pK_S^0\pi^-$ 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 $\Lambda_b^0 \to pK_S^0\pi^-$ decay

backup