Study of Λ_b^0 and Ξ_b^0 decays to $\Lambda h^+ h'^-$ and evidence for CP violation in $\Lambda_b^0 \to \Lambda K^+ K^-$ decay

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Introduction

- CP violation is required to explain the matter and antimatter asymmetry in our cosmos
- No CP violation observed in baryon decays till now

~ searches in bottom, charm baryons & hyperons

Charm baryons:

- $A_{CP}(\Lambda_c^+ \to pK^+K^-) - A_{CP}(\Lambda_c^+ \to p\pi^+\pi^-) = 0.003 \pm 0.011$ [LHCb]
- $A_{CP}(\Lambda_c^+ \to \Lambda K^+) = 0.021 \pm 0.026$ [Belle]

Hyperon:

- $A_{CP}(\Lambda \to p\pi^-) = -0.0025 \pm 0.0048$ [BESIII]

Bottom baryons:

- $A_{CP}(\Lambda_b^0 \to pK^-) = -0.020 \pm 0.023$ [LHCb Run1] , $A_{CP}(\Lambda_b^0 \to pK^-) = -0.0114 \pm 0.0076$ [LHCb Pre.]
- $A_{CP}(\Lambda_b^0 \to p\pi^-) = -0.035 \pm 0.024$ [LHCb Run1] , $A_{CP}(\Lambda_b^0 \to p\pi^-) = 0.0020 \pm 0.0091$ [LHCb Pre.]
- $A_{CP}(\Lambda_b^0 \to pK_S^0\pi^-) = 0.22 \pm 0.13$ [LHCb]
- $\Delta A_{CP}(\Lambda_b^0 \to J/\Psi p\pi^-/K^-) = 0.057 \pm 0.027$ [LHCb]
- $A_{CP}(\Lambda_b^0 \to phh'h'')$ [LHCb, see details in back up]

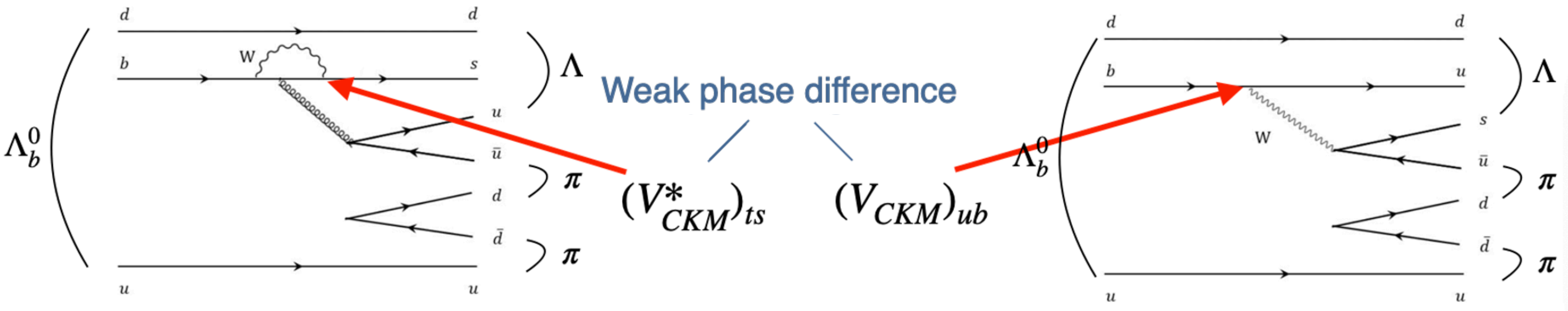
Introduction (cont.)

CPV may exist in $\Lambda_b^0\,/\Xi_b^0 \to \Lambda h^+ h'^-$ decays:

- Large CPV at the level of 10% observed in $B \to hh'h''$ decays experimentally [LHCb]
- Theoretical predictions on the $\Lambda_b^0\,/\Xi_b^0 \to \Lambda h^+ h'^-$ CPV and BF — CPV: 1% ~ 4%, BF: 10^{-6} [Link]

→ Aiming for CPV & BF in $\Lambda_b^0/\Xi_b^0 \to \Lambda hh'$ decays

Feynman diagram contributing to the $\Lambda_b^0 \to \Lambda\pi^+\pi^-$



Weak phase difference: CKM matrix
Strong phase difference: hadronic effects
} → CPV may exist

Analysis overview

Signal channels:

- Λ_b^0 decays: $\Lambda_b^0 \to \Lambda K^+K^-$, $\Lambda_b^0 \to \Lambda K^+\pi^-$, $\Lambda_b^0 \to \Lambda\pi^+\pi^-$, $\Lambda_b^0 \to \Lambda\pi^+K^-$
- Ξ_b^0 decays: $\Xi_b^0 \to \Lambda K^+K^-$, $\Xi_b^0 \to \Lambda K^+\pi^-$, $\Xi_b^0 \to \Lambda\pi^+\pi^-$, $\Xi_b^0 \to \Lambda\pi^+K^-$

Blue: BF & CPV,
Blue: BF only,
Red: not measured

Reference channel:

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

- Similar kinematics & large statistics

Run1+2 analysis

- 9fb^{-1} data
- Measurement of BF and CPV of $\Lambda_b^0\ /\Xi_b^0 \to \Lambda h^+h'^-$

An update of previous Run1 analysis

- 3fb^{-1} 2011, 2012 data [LHCb]

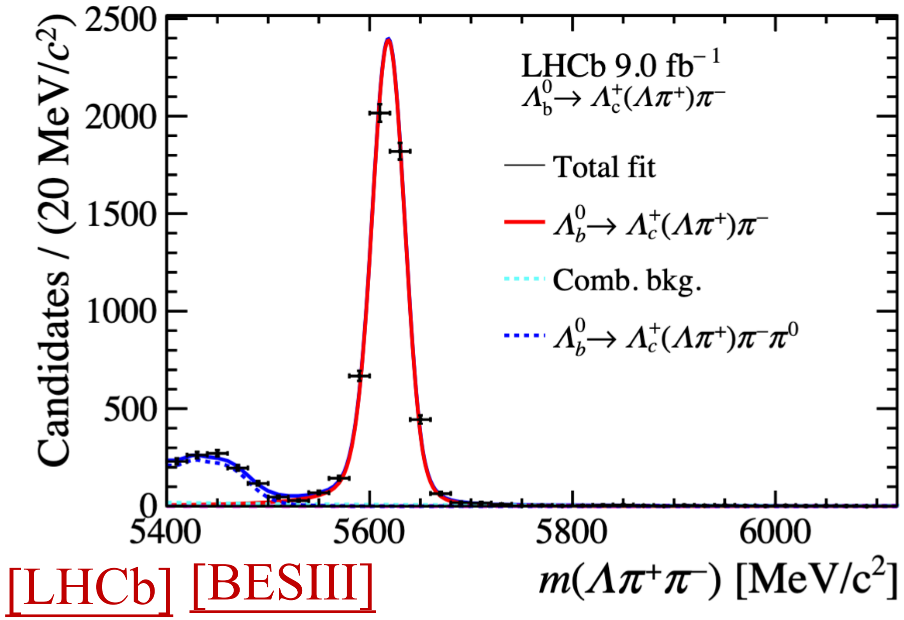
Measurements of Branching Fractions

Absolute ranching fractions of signal channels are calculated according to :

$$\frac{B\left(\Lambda_b^0\left(\Xi_b^0\right)\to \Lambda h^+h'^-\right)}{B(\Lambda_b^0\to \Lambda_c^+(\Lambda\pi^+)h'^-)} = \frac{N_{\Lambda_b^0(\Xi_b^0)\to\Lambda h^+h'^-}}{N_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}} \times \frac{\epsilon_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}}{\epsilon_{\Lambda_b^0\to\Lambda h^+h'^-}} \times \frac{f_{\Lambda_b^0}}{f_{\Lambda_b^0(\Xi_b^0)}}$$

Branching fraction (in addition to A_{CP}) offers important information to the internal dynamics

In LHCb, we measure w.r.t. control channels (relative branching fraction) to reduce systematic uncertainties.



Absolute branching fractions of control channel [LHCb] [BESIII]

$$\mathcal{B}\left(\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-\right) = (6.0\pm 0.6)\times 10^{-5}$$

Signal extraction

$$\frac{B\left(\Lambda_b^0(\Xi_b^0) \to \Lambda h^+ h'^-\right)}{B(\Lambda_b^0 \to \Lambda_c^+(\Lambda\pi^+)h'^-)} = \frac{N_{\Lambda_b^0(\Xi_b^0)\to\Lambda h^+ h'^-}}{N_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}} \times \frac{\epsilon_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}}{\epsilon_{\Lambda_b^0\to\Lambda h^+ h'^-}} \times \frac{f_{\Lambda_b^0}}{f_{\Lambda_b^0(\Xi_b^0)}}$$

Fit model: Simultaneous fit applied

Signal Model

- Sum of two Crystal Ball functions
- Mean and width shared among all decays

Mis-ID background

- Sum of two Crystal Ball functions

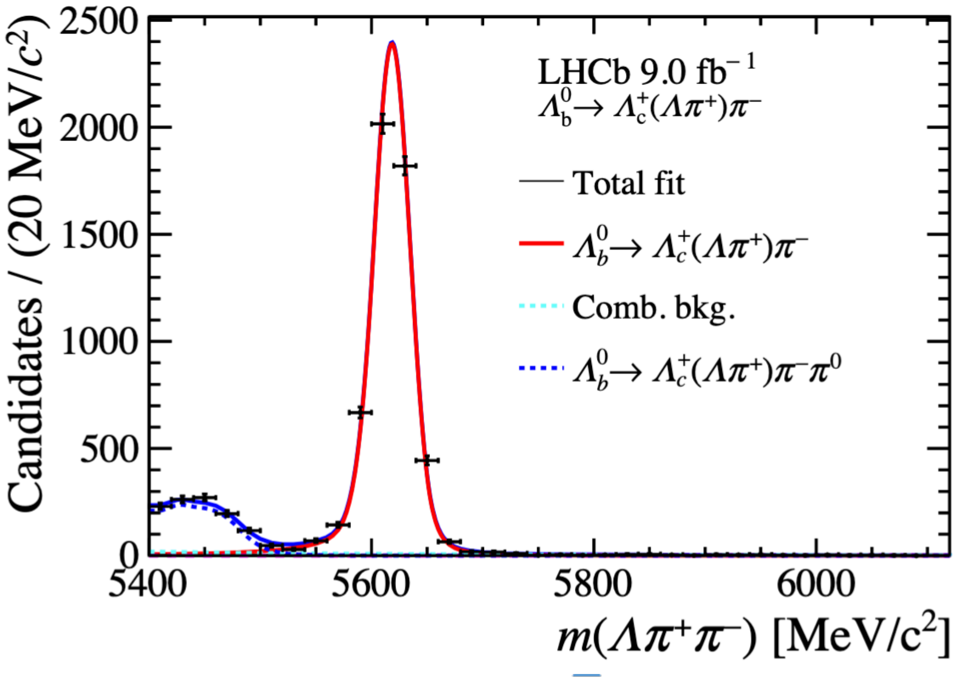
Partially reconstructed background

- Argus convolved gaussian

Combinatorial background

- Parameters shared among all decays

~ 5200 signals

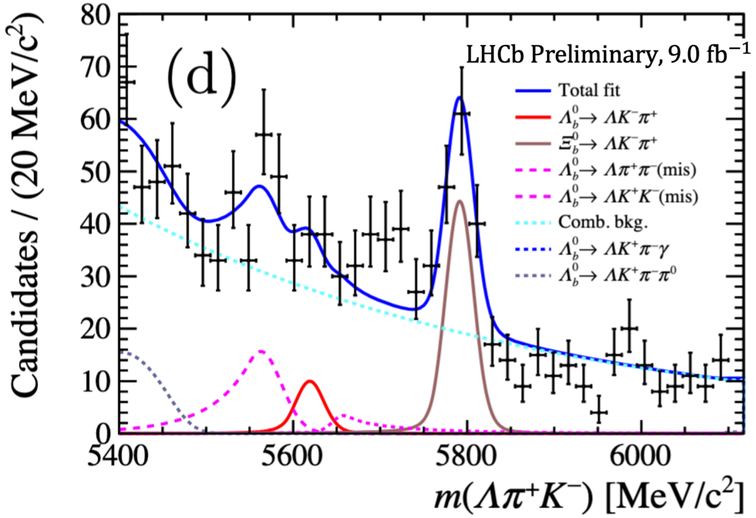


Fit results

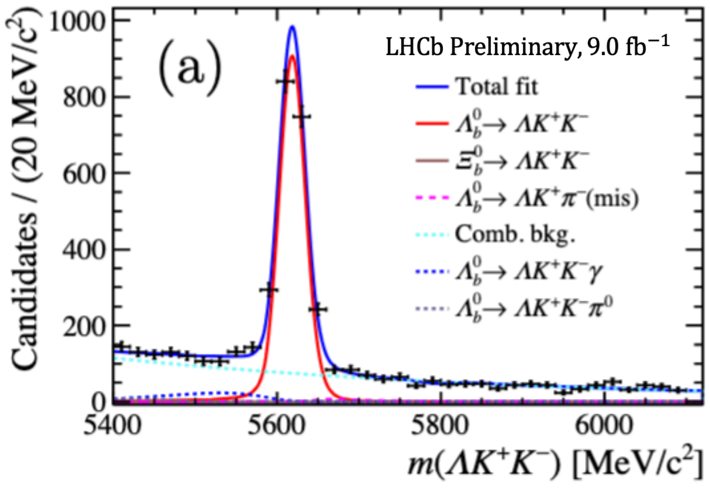
$$\frac{\mathcal{B}\left(\Lambda_b^0(\Xi_b^0)\to\Lambda h^+h'^-\right)}{\mathcal{B}\left(\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)h'^-\right)} = \frac{N_{\Lambda_b^0(\Xi_b^0)\to\Lambda h^+h'^-}}{N_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}} \times \frac{\epsilon_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}}{\epsilon_{\Lambda_b^0\to\Lambda h^+h'^-}} \times \frac{f_{\Lambda_b^0}}{f_{\Lambda_b^0(\Xi_b^0)}}$$

Signal channels:

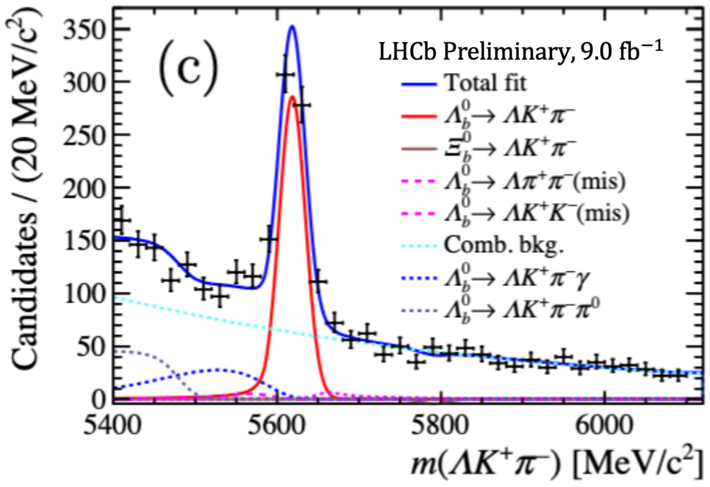
- Λ_b^0 decays: $\Lambda_b^0\to\Lambda K^+K^-$, $\Lambda_b^0\to\Lambda K^+\pi^-$, $\Lambda_b^0\to\Lambda\pi^+\pi^-$, $\Lambda_b^0\to\Lambda\pi^+K^-$
- Ξ_b^0 decays: $\Xi_b^0\to\Lambda K^+K^-$, $\Xi_b^0\to\Lambda K^+\pi^-$, $\Xi_b^0\to\Lambda\pi^+\pi^-$, $\Xi_b^0\to\Lambda\pi^+K^-$



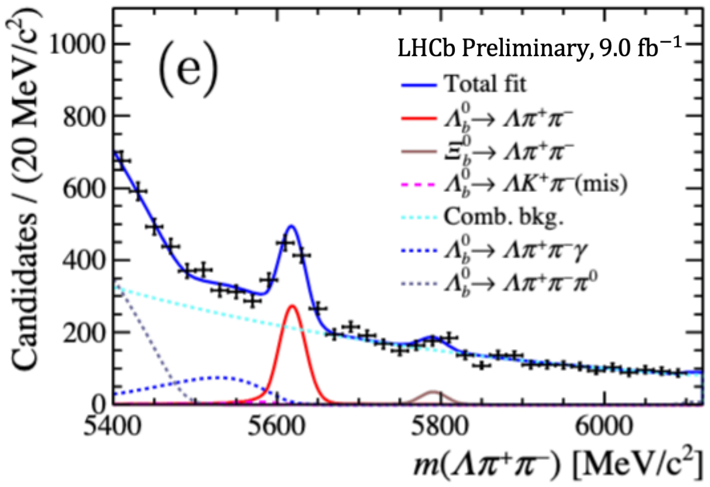
$\Xi_b^0\to\Lambda\pi^+K^-$



$\Lambda_b^0\to\Lambda K^+K^-$



$\Lambda_b^0\to\Lambda\pi^+\pi^-$



$\Lambda_b^0\to\Lambda K^+\pi^-$

Fit results (cont.)

Λ_b^0 decays ~ 1000 events
Ξ_b^0 decays ~ 100 events

Yields and significance:
(using Wilks' theorem)

Channel	Yield	Significance
$\Lambda_b^0 \to \Lambda\pi^+\pi^-$	$(6.4 \pm 0.4) \times 10^2$	$> 10\sigma$, first obs.
$\Lambda_b^0 \to \Lambda K^+\pi^-$	$(6.18 \pm 0.32) \times 10^2$	$> 10\sigma$
$\Lambda_b^0 \to \Lambda K^+K^-$	$(1.92 \pm 0.05) \times 10^3$	$> 10\sigma$
$\Xi_b^0 \to \Lambda\pi^+\pi^-$	$(5.6 \pm 2.7) \times 10^1$	4.0σ, first evidence
$\Xi_b^0 \to \Lambda\pi^+K^-$	$(1.19 \pm 0.15) \times 10^2$	10.4σ, first obs.
$\Xi_b^0 \to \Lambda K^+K^-$	$(1.2 \pm 0.9) \times 10^1$	1.7σ

Measurements of Branching Fractions

Absolute ranching fractions of signal channels are calculated according to :

$$\frac{B\left(\Lambda_b^0\left(\Xi_b^0\right) \to \Lambda h^+ h'^-\right)}{B\left(\Lambda_b^0 \to \Lambda_c^+(\Lambda\pi^+)h'^-\right)} = \frac{N_{\Lambda_b^0(\Xi_b^0)\to\Lambda h^+ h'^-}}{N_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}} \times \frac{\epsilon_{\Lambda_b^0\to\Lambda_c^+(\Lambda\pi^+)\pi^-}}{\epsilon_{\Lambda_b^0\to\Lambda h^+ h'^-}} \times \frac{f_{\Lambda_b^0}}{f_{\Lambda_b^0(\Xi_b^0)}}$$

Efficiencies determined from simulation with corrections using data-driven methods

- Particle ID, trigger, tracking : using control channels from $\boldsymbol{D^{*+} \to D^0(\to K^-\pi^+\pi^+)}$..
- Dalitz plot corrections: difference on Dalitz plot distribution between data and simulation

Fragmentation fraction [LHCb]

$$\frac{f_{\Xi_b}}{f_{\Lambda_b}} = (6.7 \pm 0.5 \pm 0.5 \pm 2.0) \times 10^{-2} \text{ for 7,8 TeV}$$
$$= (8.2 \pm 0.7 \pm 0.6 \pm 2.5) \times 10^{-2} \text{ for 13 TeV}$$

Results for Branching Fractions

Results of branching fractions:

$$\mathcal{B}\left(\Lambda_b^0 \to \Lambda\pi^+\pi^-\right) = (\quad 5.3 \pm 0.4(\text{stat.}) \pm 0.5(\text{syst.}) \pm 0.5(\text{norm.})) \times 10^{-6}$$

$$\mathcal{B}\left(\Lambda_b^0 \to \Lambda K^+\pi^-\right) = (\quad 4.6 \pm 0.2(\text{stat.}) \pm 0.4(\text{syst.}) \pm 0.5(\text{norm.})) \times 10^{-6}$$

$$\mathcal{B}\left(\Lambda_b^0 \to \Lambda K^+K^-\right) = (\quad 10.7 \pm 0.3(\text{stat.}) \pm 0.4(\text{syst.}) \pm 1.1(\text{norm.})) \times 10^{-6}$$

$$\mathcal{B}\left(\Xi_b^0 \to \Lambda\pi^+\pi^-\right) = (\quad 11.0 \pm 2.6(\text{stat.}) \pm 1.4(\text{syst.}) \pm 3.8(\text{norm.})) \times 10^{-6}$$

$$\mathcal{B}\left(\Xi_b^0 \to \Lambda\pi^+K^-\right) = (\quad 10.4 \pm 1.4(\text{stat.}) \pm 1.2(\text{syst.}) \pm 3.5(\text{norm.})) \times 10^{-6}$$

$$\mathcal{B}\left(\Xi_b^0 \to \Lambda K^+K^-\right) = (\quad 1.2 \pm 0.7(\text{stat.}) \pm 0.6(\text{syst.}) \pm 0.4(\text{norm.})) \times 10^{-6}$$

$$\mathcal{B}\left(\Xi_b^0 \to \Lambda K^+K^-\right) < \quad 2.4\ (\ 2.8\ ) \times 10^{-6} \quad \text{at 90 (95)\% confidence level}$$

Consistent with previous Run1 analysis

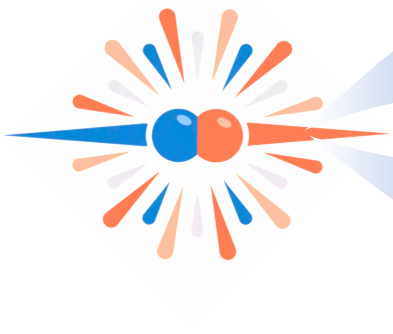
$$\mathcal{B}(\Lambda_b^0 \to \Lambda\pi^+\pi^-) = (4.6 \pm 1.2 \pm 1.4 \pm 0.6) \times 10^{-6}\,,$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda K^+\pi^-) = (5.6 \pm 0.8 \pm 0.8 \pm 0.7) \times 10^{-6}\,,$$

$$\mathcal{B}(\Lambda_b^0 \to \Lambda K^+K^-) = (15.9 \pm 1.2 \pm 1.2 \pm 2.0) \times 10^{-6}\,,$$

Methodology for A_{CP} measurement

p-p collision



Λ_b^0 production: N^+_{prod} × Λ_b^0 decay → $\Lambda h^+ h'^-$: $\Gamma^+/\Gamma_{\text{tot}}$ × Detection $\Lambda h^+ h'^-$: ϵ^+_{exp} = N^+_{raw} (Λ_b^0)

$\bar{\Lambda}_b^0$ production: N^-_{prod} × $\bar{\Lambda}_b^0$ decay → $\Lambda h^+ h'^-$: $\Gamma^-/\bar{\Gamma}_{\text{tot}}$ Detection $\Lambda h^+ h'^-$: ϵ^-_{exp} = N^-_{raw} $(\bar{\Lambda}_b^0)$

$$A_{\text{prod}} = \frac{N^+_{\text{prod}} - N^-_{\text{prod}}}{N^+_{\text{prod}} + N^-_{\text{prod}}} \qquad A_{CP} = \frac{\Gamma^+/\Gamma_{\text{tot}} - \Gamma^-/\bar{\Gamma}_{\text{tot}}}{\Gamma^+/\Gamma_{\text{tot}} + \Gamma^-/\bar{\Gamma}_{\text{tot}}} \qquad A_{\text{exp}} = \frac{\epsilon^+_{\text{exp}} - \epsilon^-_{\text{exp}}}{\epsilon^+_{\text{exp}} + \epsilon^-_{\text{exp}}} \qquad A_{\text{raw}} = \frac{N^+_{\text{raw}} - N^-_{\text{raw}}}{N^+_{\text{raw}} + N^-_{\text{raw}}}$$

$$A_{\text{prod}} + A_{CP} + A_{\text{exp}} \approx A_{\text{raw}}$$

- Procedure：

1. Extract signal yields N^+_{raw} 、 N^-_{raw} ➡ Raw asymmetry A_{raw}
2. Corrections on A_{prod}、 A_{exp} ➡ $A_{CP} \approx A_{\text{raw}} - A_{\text{prod}} - A_{\text{exp}}$

ΔA_{CP} measurement: reduce systematics

To reduce systematic uncertainties, A_{CP} is measured according to:

$$\Delta A_{\mathrm{CP}} = A_{CP}(signal) - A_{CP}(control)$$

Same mother particle & similar daughter partcle → Correction terms greatly cancelled.

$$= A_{\mathrm{raw}}(signal) - A_{\mathrm{raw}}(control) - \Delta A_{\mathrm{exp}} - \Delta A_{\mathrm{P}}$$

Raw results: $A_{\mathrm{raw}}(signal) - A_{\mathrm{raw}}(control)$

Corrections: $\Delta A_{\mathrm{exp}} - \Delta A_{\mathrm{P}}$

- $A_{CP}(control) = 0$ within the precision of our analysis.
- $A_{\mathrm{P}}, A_{\mathrm{exp}}$: measured by LHCb as a function of y, PT, at the level of 1%.
- ΔA_{P}, ΔA_{exp}: mostly cancelled, small residual due to the differences between signal channel and control channel. Both ΔA_{P} and ΔA_{exp} are consistent with 0

Channel	ΔA_{P} (%)	ΔA_{exp} (%)
$\Lambda_b^0 \to \Lambda\pi^+\pi^-$	0.1 ± 0.1	0.1 ± 0.9
$\Lambda_b^0 \to \Lambda K^+\pi^-$	0.2 ± 0.2	1.4 ± 1.0
$\Lambda_b^0 \to \Lambda K^+K^-$	-0.2 ± 0.2	0.0 ± 0.9
$\Xi_b^0 \to \Lambda K^-\pi^+$	-5.2 ± 4.0	0.3 ± 1.6

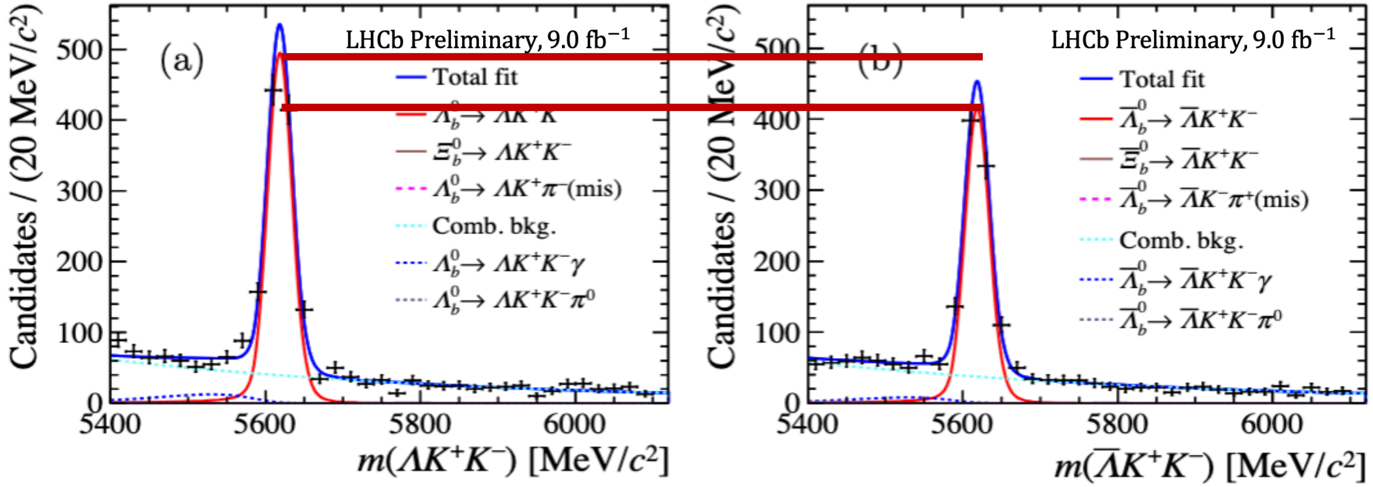
Global A_{CP} results

$$\Delta\mathcal{A}^{CP}\left(\Lambda_b^0 \to \Lambda\pi^+\pi^-\right) = -0.013 \pm 0.053 \pm 0.018,$$
$$\Delta\mathcal{A}^{CP}\left(\Lambda_b^0 \to \Lambda K^+\pi^-\right) = -0.118 \pm 0.045 \pm 0.021,$$
$$\Delta\mathcal{A}^{CP}\left(\Xi_b^0 \to \Lambda K^-\pi^+\right) = 0.27 \pm 0.12 \pm 0.05,$$

$\Delta\mathcal{A}^{CP}\left(\Lambda_b^0 \to \Lambda K^+K^-\right) = 0.083 \pm 0.023 \pm 0.016$ Significance: 3.1σ

Evidence of CPV observed in $\Lambda_b^0 \to \Lambda K^+K^-$

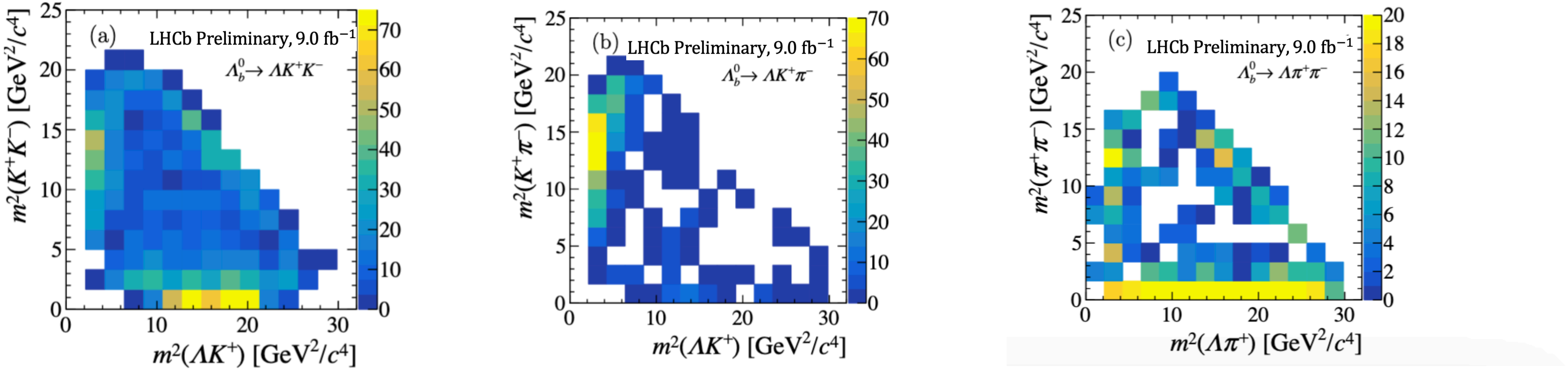
Fit results for $\Lambda_b^0 \to \Lambda K^+K^-$



Further explore the CPV of $\Lambda_b^0 \to \Lambda K^+K^-$ local regions

Looking into Dalitz plot

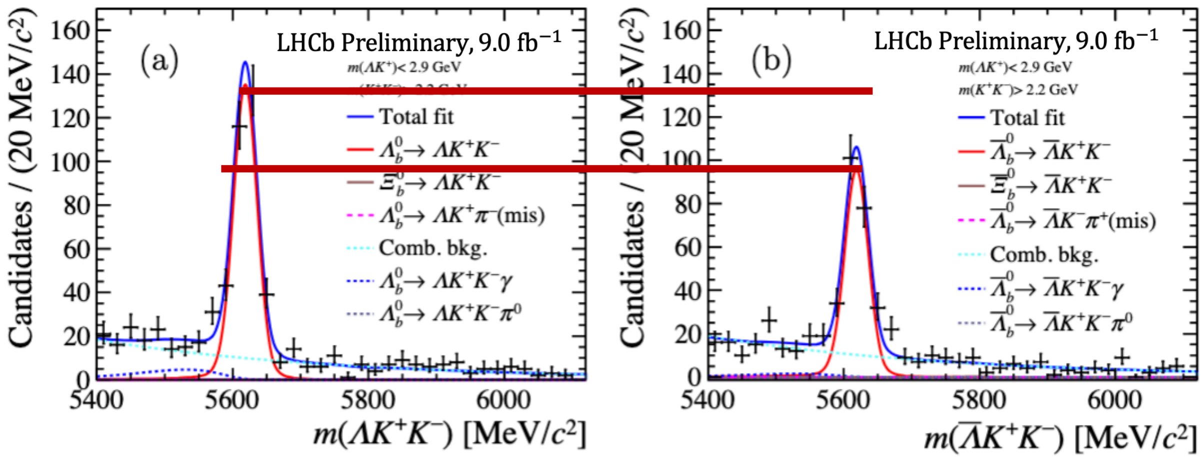
$\Lambda_b^0 \rightarrow \Lambda K^+ K^-$ $\Lambda_b^0 \rightarrow \Lambda K^+ \pi^-$ $\Lambda_b^0 \rightarrow \Lambda \pi^+ \pi^-$



Local resonant states & CP asymmetries

Channel	$m(h^+h'^-)$	$m(\Lambda h^+)$	$\Delta\mathcal{A}^{CP}$
$\Lambda_b^0 \to \Lambda\phi\,(\to K^+K^-)$	$< 1.10\,\mathrm{GeV}/c^2$	—	$0.150 \pm 0.055 \pm 0.021$
$\Lambda_b^0 \to N^{*+}(\to \Lambda K^+)K^-$	$> 2.20\,\mathrm{GeV}/c^2$	$< 2.90\,\mathrm{GeV}/c^2$	$0.165 \pm 0.048 \pm 0.017$
$\Lambda_b^0 \to N^{*+}(\to \Lambda K^+)\pi^-$	—	$< 2.30\,\mathrm{GeV}/c^2$	$-0.078 \pm 0.051 \pm 0.027$
$\Lambda_b^0 \to \Lambda f\,(\to \pi^+\pi^-)$	$< 1.70\,\mathrm{GeV}/c^2$	—	$0.088 \pm 0.069 \pm 0.021$

Looking into Dalitz plot ($\Lambda_b^0 \to \Lambda K^+ K^-$)



$\Lambda_b^0 \to N^{*+}(\to \Lambda K^+)K^-$ region

$$\Delta\mathcal{A}_{CP} = 0.165 \pm 0.048 \pm 0.017$$

First evidence of CP violation in local resonant region, 3.2σ

possible $N - \pi$ resonances?

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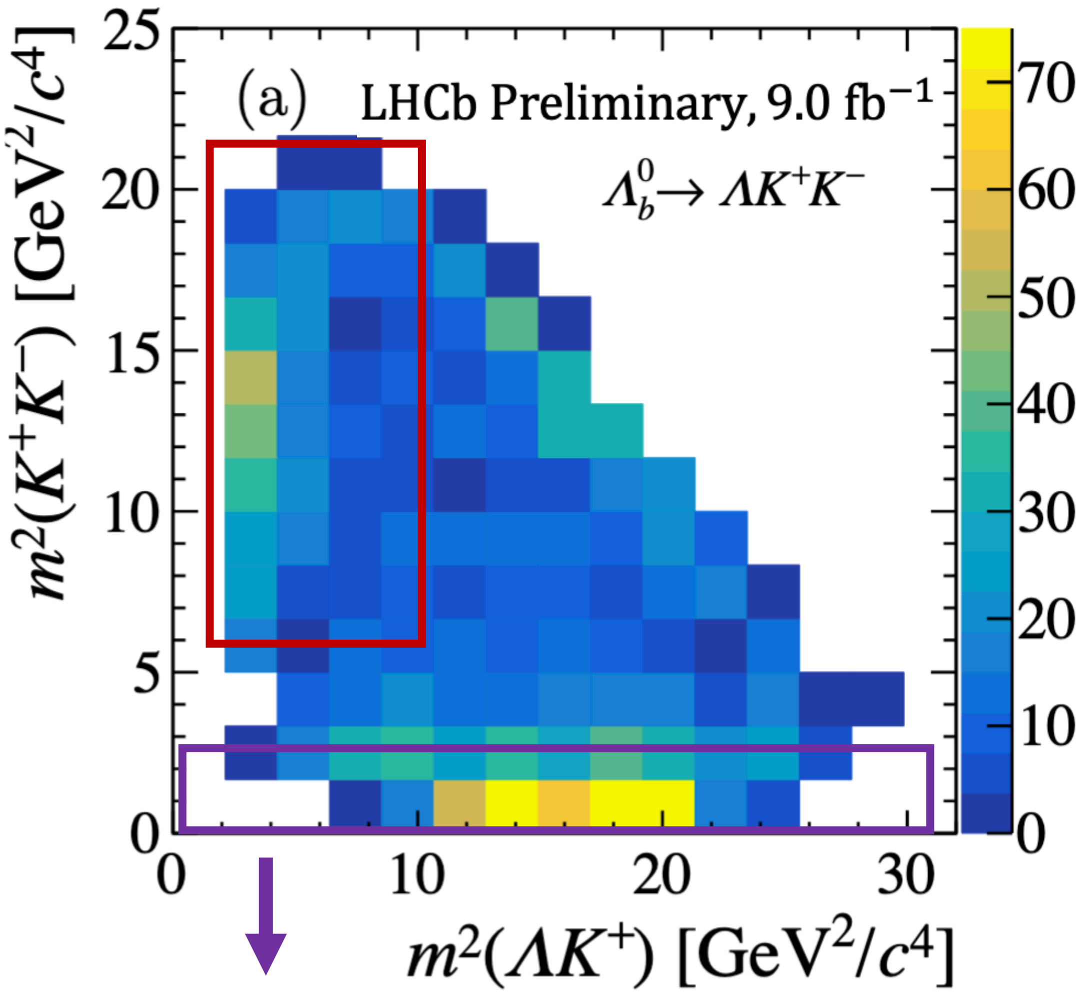
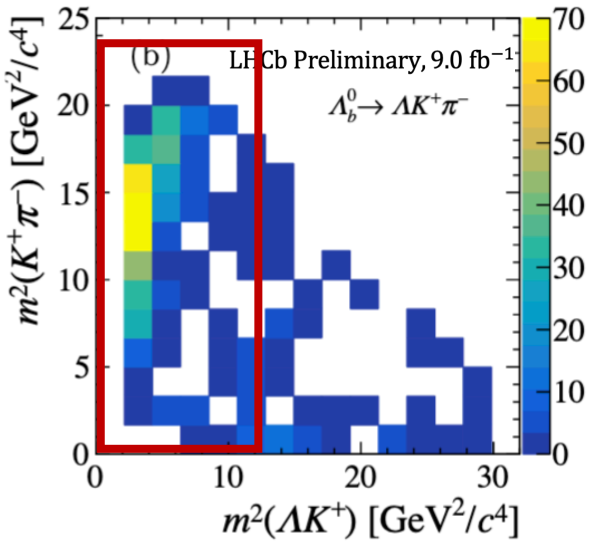


$\Lambda\phi/f(1500)$

$$A_{CP} = 0.150 \pm 0.055 \pm 0.021(2.5\sigma)$$

Looking into Dalitz plot ($\Lambda_b^0 \to \Lambda h^+ \pi^-$)



Region N^{*+}

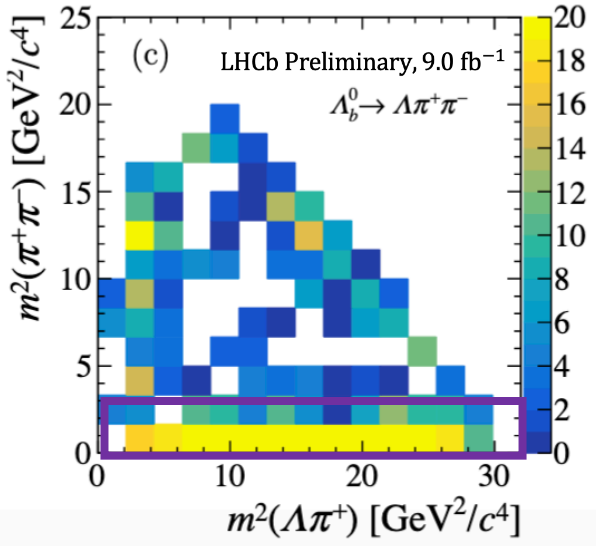
$\Lambda_b^0 \to \Lambda K^+ \pi^-$

Mainly $\boldsymbol{\Lambda_b^0 \to N^{*+}\pi^-}$

Small contribution from $\boldsymbol{\Lambda_b^0 \to \Lambda K^*}$

$A_{\rm CP} = -0.078 \pm 0.051 \pm 0.027\ (1.2\,\sigma)$

No significant CPV observed



Region ϕ/f

$\Lambda_b^0 \to \Lambda \pi^+ \pi^-$

Mainly $\boldsymbol{\Lambda_b^0 \to \Lambda f_0(980)}$, $\boldsymbol{\Lambda_b^0 \to \Lambda f_2(1270)}$

$A_{\rm CP} = -0.088 \pm 0.069 \pm 0.021\ (1.4\,\sigma)$

No significant CPV observed

A_{CP} in adaptive binning scheme

2D adaptive binning on Dalitz plot ($m(h^+h^-)$ vs. $m(\Lambda h^+)$) based on signal numbers

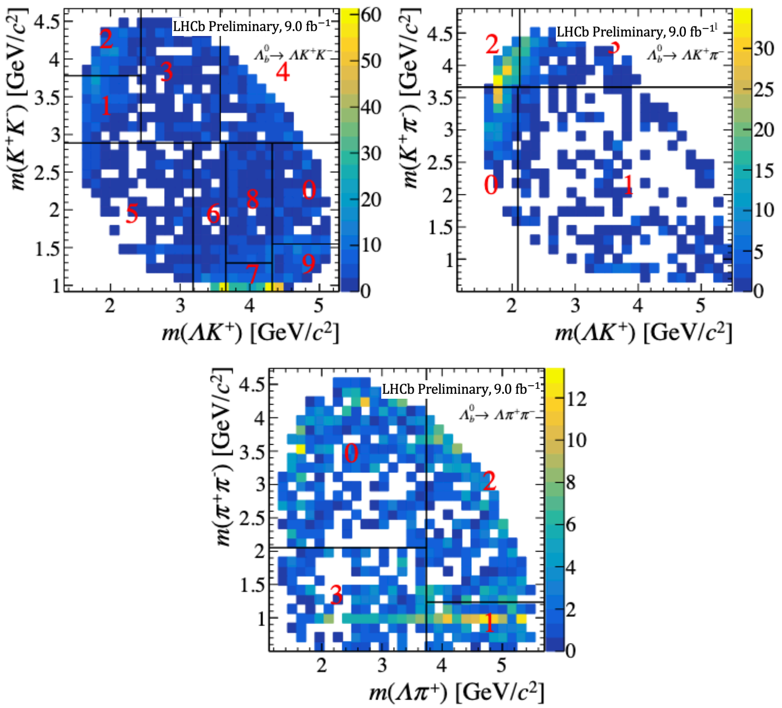
Number of bins (about 200 events per bin)

$\Lambda_b^0 \to \Lambda K^+K^-$:10

$\Lambda_b^0 \to \Lambda K^+\pi^-$:4

$\Lambda_b^0 \to \Lambda \pi^+\pi^-$:4

only measure three Λ_b^0 decays



A_{CP} results in adaptive binning scheme

Channel	Bin	$\mathcal{A}_{CP}$
$\Lambda_b^0 \to \Lambda K^+K^-$	0	$0.017 \pm 0.092 \pm 0.025$
$\Lambda_b^0 \to \Lambda K^+K^-$	1	$0.188 \pm 0.075 \pm 0.023$
$\Lambda_b^0 \to \Lambda K^+K^-$	2	$0.062 \pm 0.077 \pm 0.022$
$\Lambda_b^0 \to \Lambda K^+K^-$	3	$0.064 \pm 0.093 \pm 0.024$
$\Lambda_b^0 \to \Lambda K^+K^-$	4	$0.088 \pm 0.077 \pm 0.022$
$\Lambda_b^0 \to \Lambda K^+K^-$	5	$0.061 \pm 0.089 \pm 0.024$
$\Lambda_b^0 \to \Lambda K^+K^-$	6	$0.066 \pm 0.088 \pm 0.024$
$\Lambda_b^0 \to \Lambda K^+K^-$	7	$0.168 \pm 0.070 \pm 0.021$
$\Lambda_b^0 \to \Lambda K^+K^-$	8	$-0.002 \pm 0.080 \pm 0.023$
$\Lambda_b^0 \to \Lambda K^+K^-$	9	$0.025 \pm 0.074 \pm 0.022$
$\Lambda_b^0 \to \Lambda K^+\pi^-$	0	$-0.153 \pm 0.079 \pm 0.027$
$\Lambda_b^0 \to \Lambda K^+\pi^-$	1	$-0.284 \pm 0.188 \pm 0.041$
$\Lambda_b^0 \to \Lambda K^+\pi^-$	2	$-0.006 \pm 0.062 \pm 0.028$
$\Lambda_b^0 \to \Lambda K^+\pi^-$	3	$-0.264 \pm 0.125 \pm 0.030$
$\Lambda_b^0 \to \Lambda \pi^+\pi^-$	0	$-0.483 \pm 0.200 \pm 0.043$
$\Lambda_b^0 \to \Lambda \pi^+\pi^-$	1	$0.147 \pm 0.092 \pm 0.026$
$\Lambda_b^0 \to \Lambda \pi^+\pi^-$	2	$0.058 \pm 0.114 \pm 0.028$
$\Lambda_b^0 \to \Lambda \pi^+\pi^-$	3	$0.067 \pm 0.111 \pm 0.028$

No significant local variations of A_{CP} observed.

Conclusion

- Measurements of BF & CPV for Λ_b^0 /$\Xi_b^0 \to \Lambda h^+ h'^-$ channels

- Evidence for A_{CP} observed in $\Lambda_b^0 \to \Lambda K^+ K^-$ channel for the first time, both from the global A_{CP} and in local N^{*+} region.

$\rightarrow$ A solid step towards establishment of CP violation in baryon decays.

- First observation of $\Lambda_b^0 \to \Lambda \pi^+ \pi^-$ and $\Xi_b^0 \to \Lambda \pi^+ K^-$ channels
- First evidence for $\Xi_b^0 \to \Lambda \pi^+ \pi^-$

Thanks for listening!

Back up

CPV asymmetry links

[LHCb] : Observation of the suppressed $\Lambda^0_b \to DpK^-$ decay with $D \to K^+\pi^-$ and measurement of its CP asymmetry

[LHCb] : Measurement of matter-antimatter differences in beauty baryon decays

[LHCb] : Search for CP violation using triple product asymmetries in $\Lambda^0_b \to pK^-\pi^+\pi^-$, $\Lambda^0_b \to pK^-K^+K^-$, and $\Xi^0_b \to pK^-K^-\pi^+$ decays

[LHCb] : Measurement of CP asymmetries in charmless four-body Λ^0_b and Ξ^0_b decays

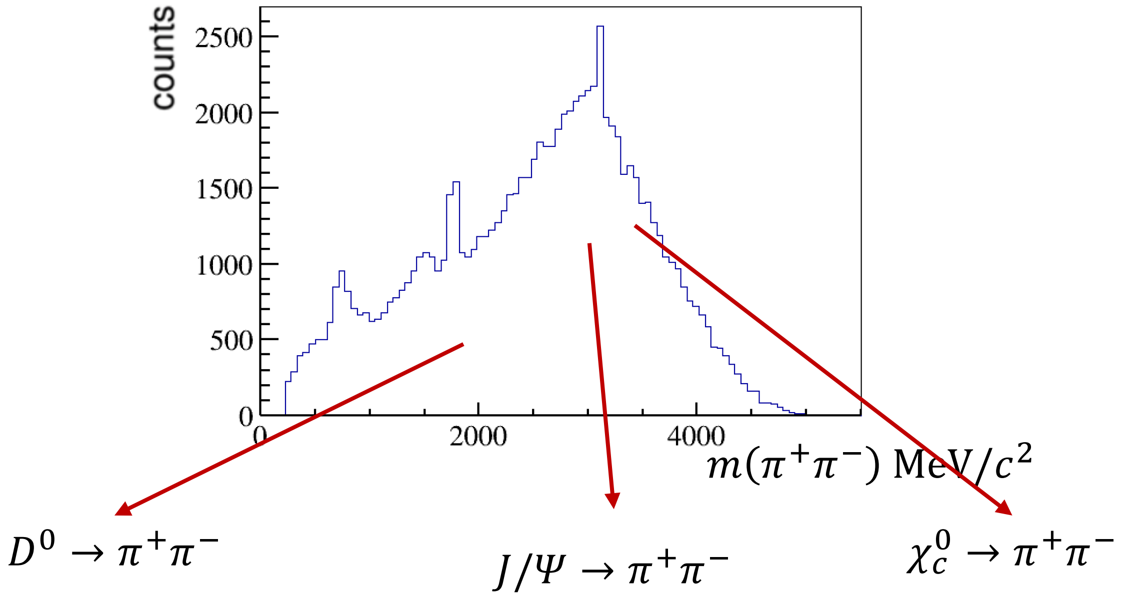
[LHCb] : LHCb collaboration, R. Aaij et al., Search for CP violation and observation of P violation in $\Lambda^0_b \to p\pi^-\pi^+\pi^-$ decays

Selection: Preselection and mass vetoes

Mass vetoes

- Narrow resonances: K_S^0, D^0, Λ_c^+, Ξ_c^+, J/ψ and χ_c^0 ← Add veto cuts on states

$m(\pi^+\pi^-)$ of $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ before mass veto



Selection: BDT & PID selection

Boosted Decision Tree (BDT)

- Training sample:
  Signal:
  MC sample of $\Lambda_b^0 \to \Lambda\pi^+\pi^-$
  Background:
  Sideband of $\Lambda_b^0 \to \Lambda\pi^+\pi^-$ data
  $[5800, 6100]\ \mathrm{MeV}/c^2$
- Applied to all $\Lambda h^+ h'^-$ channels
- Optimize BDT and PID cuts simultaneously

- Training variables:
  kinematics, vertex, LL DD separate …

All channels are optimized independently

- Significance F.o.M = $\frac{N_{sig}}{\sqrt{N_{\mathrm{sig}}+N_{\mathrm{bkg}}}}$ for Λ_b^0 decays
- Punzi F.o.M = $\frac{N_{\mathrm{sig}}}{2.5+\sqrt{N_{\mathrm{bkg}}}}$ for Ξ_b^0 decays

Signal extraction

Fit model: Simultaneous fit applied

Signal Model
- Sum of two Crystal Ball functions
- Parameters extracted from MC (except mean and width)
- Mean and width shared among all decays

Mis-ID background
- Sum of two Crystal Ball functions
- Parameters extracted from MC
- Ratio of Signal and mis-ID fixed

Partially reconstructed background
- Argus convolved gaussian
- Parameters extracted from MC

Combinatorial background
- Parameters shared among all decays

Efficiencies

Total efficiency is calculated with:

$$\epsilon_{Total} = \epsilon_{\text{acceptance}} \times \epsilon_{\text{stripping/reconstruction}} \times \epsilon_{\text{trigger}} \times \epsilon_{\text{offline-selection}} \times \epsilon_{\text{PID}}$$

Efficiency measurements: Based on simulation samples

- corrections on Λ_b^0 p_T, η (y) variables
- PID efficiency:
  further simulated with recalibrated MC
  (Data-driven)
- Efficiency evaluated in bins of Dalitz plot,
  perform per-event efficiency corrections

$$\bar{\epsilon} = \frac{\sum_i \omega_i}{\sum_i \omega_i / \epsilon_i},$$

ω_i: sweight of data

Systematic uncertainties

Systematic uncertainties from signal extraction

- Control channel yields
- Mass window size of veto cuts
- Fit models

For BF measurements, results are absolute systematic uncertainty for BF ratios

Channels	PhSp	Fit	Veto	PID	Ref. Yield	Eff.	Total
$\Lambda_b^0 \to \Lambda\pi^+\pi^-$	0.0804	0.0436	0.0061	0.0048	0.0372	0.0148	0.1001
$\Lambda_b^0 \to \Lambda K^+\pi^-$	0.0657	0.0224	0.0079	0.0009	0.0288	0.0129	0.0766
$\Lambda_b^0 \to \Lambda K^+K^-$	0.0254	0.0189	0.0045	0.0041	0.0175	0.0131	0.0390
$\Xi_b^0 \to \Lambda\pi^+\pi^-$	0.1043	0.1022	0.0196	0.0038	0.0519	0.0165	0.1571
$\Xi_b^0 \to \Lambda K^-\pi^+$	0.1304	0.0967	0.0034	0.0031	0.0376	0.0184	0.1677
$\Xi_b^0 \to \Lambda K^+K^-$	0.1133	1.1222	0.5700	0.0013	0.0272	0.0243	1.2643

For CPV measurements, Results are systematic uncertainty for A_{CP} (unit 1)

Channel	Fit	Shape	Correction	Control	Veto	Total
$\Lambda_b^0 \to \Lambda\pi^+\pi^-$	0.007	0.005	0.009	0.013	0.004	0.018
$\Lambda_b^0 \to \Lambda K^+\pi^-$	0.011	0.005	0.010	0.013	0.002	0.021
$\Lambda_b^0 \to \Lambda K^+K^-$	0.003	0.002	0.009	0.013	0.002	0.016
$\Xi_b^0 \to \Lambda K^+\pi^-$	0.022	0.009	0.043	0.013	0.006	0.051

Systematic uncertainties

Systematic uncertainty from efficiency

- MC sample size
- Phase space binning scheme
- PID efficiency

For BF measurements, results are relative systematic uncertainty for BF ratios

Channels	PhSp	Fit	Veto	PID	Ref. Yield	Eff.	Total
$\Lambda_b^0 \to \Lambda\pi^+\pi^-$	0.0804	0.0436	0.0061	0.0048	0.0372	0.0148	0.1001
$\Lambda_b^0 \to \Lambda K^+\pi^-$	0.0657	0.0224	0.0079	0.0009	0.0288	0.0129	0.0766
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