# CP-violation in decay

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LHCb Implications Workshop

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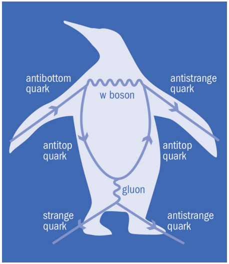
# CP-violation in decay

- $b$-hadron decays without charm in the final state can have similar sized tree ($A_1$) and penguin ($A_2$) contributions
- Maximise potential for CP violation in decay (different weak phases, $\phi = \phi_1 - \phi_2$)
- Multi-body final states also proceed via numerous intermediate resonances - variation in strong phase, $\delta = \delta_1 - \delta_2$, across Dalitz plot




$$\mathcal{A}_{\mathrm{CP}} = \frac{2|A_1||A_2| \sin\delta \sin\phi}{|A_1|^2+|A_2|^2+2|A_1||A_2| \cos\delta \cos\phi}$$

See talk by F.Dordei for additional CPV measurements

# Techniques

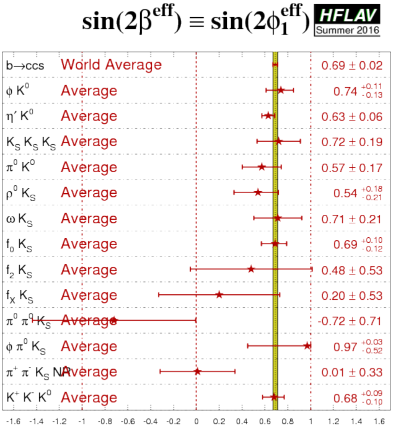
- In principle, the most promising investigations are in multi-body decays - many techniques used to analyse them:
  - **Phase-space integrated CP-asymmetries** [arXiv:1603.00413]
  - **Amplitude fits - three and four-body**
  - **Binned phase-space asymmetries** [arXiv:1408.5373]
  - **Triple-product asymmetries** [arXiv:1609.05216, arXiv:1603.02870]
  - **Kernel based two-sample hypothesis testing ('Energy test')** [arXiv:1410.4170]
- All of these used in upcoming searches for CP-violation, using the decays described in this talk

# $B^0_{(s)} \to K^0_{\mathrm{S}} h^+ h^-$ branching fractions

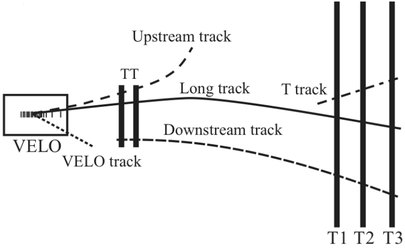
[arXiv:1707.01665 , to appear in JHEP]

# $B^0_{(s)} \to K^0_S h^+ h^-$ decays

- Loop-dominated avenue to measure the CKM angle $\beta$, via $B \to \phi K^0_S$ (or $B \to \rho^0 K^0_S$, ...) [arXiv:hep-ph/9704277].
- Can also obtain the CKM angle $\gamma$ from isospin or flavour SU(3) symmetry relations between decay modes [arXiv:hep-ph/0601233, arXiv:1303.0846].
- Arguments can also be reversed to provide information on hadronic parameters in $B \to K^* \pi$ [arXiv:1704.01596].



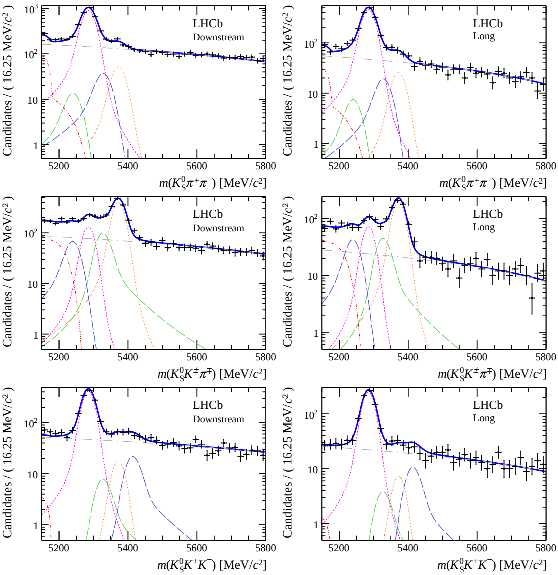
- All $B^0 \to K^0_S h^+ h^-$ decays observed at the B-factories [arXiv:1003.0640].
- $B^0_s \to K^0_S \pi^+ \pi^-$ and $B^0_s \to K^0_S K^{\pm} \pi^{\mp}$ observed with $1 \mathrm{fb}^{-1}$ of 2011 LHCb data [arXiv:1307.7648].
- Aim for the $3 \mathrm{fb}^{-1}$ update is to make the most precise measurement of the branching fractions, and make an observation of $B^0_s \to K^0_S K^+ K^-$.




$K^0_S$-mesons reconstructed from two *downstream* or *long* tracks.

# $B^0_{(s)} \to K^0_S h^+ h^-$ branching fractions

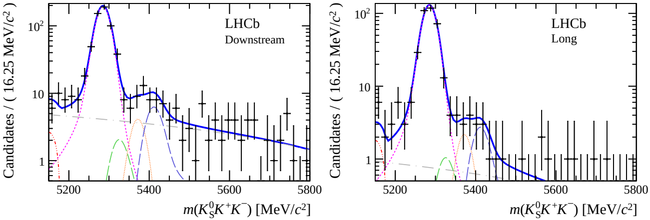
[arXiv:1707.01665 , to appear in JHEP]




Yields:

- $B^0 \to K^0_S\pi^+\pi^-$: $4177 \pm 80$
- $B^0 \to K^0_S K^\pm\pi^\mp$: $421 \pm 29$
- $B^0 \to K^0_S K^+K^-$: $1818 \pm 49$
- $B^0_s \to K^0_S\pi^+\pi^-$: $220 \pm 22$
- $B^0_s \to K^0_S K^\pm\pi^\mp$: $1668 \pm 50$

- Selection separately optimised for the search for $B^0_s \to K^0_S K^+ K^-$ (dashed blue curve):

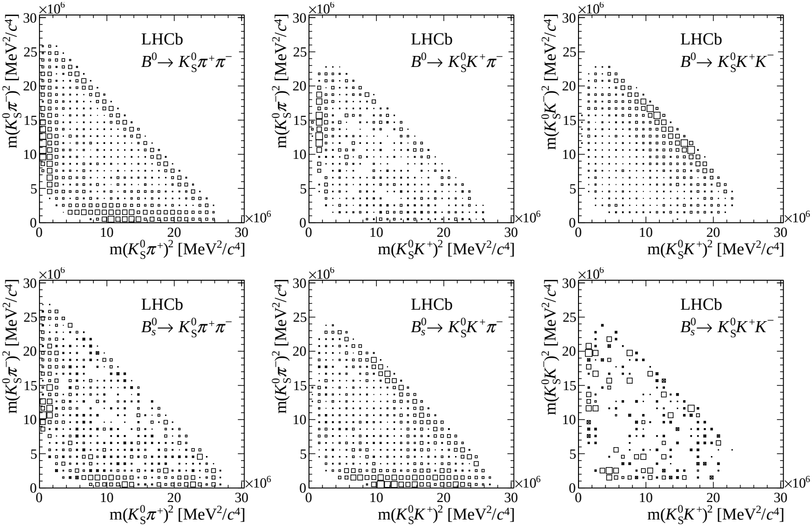



Yield of **19 ± 7** events (2.5$\sigma$ stat. + syst.)

- Efficiencies calculated using simulated data, using the corresponding background subtracted phase-space distributions - data-driven corrections for particle ID, L0 trigger, and tracking
- Dominant systematics from the combinatorial background fit model, and the knowledge of the L0 trigger efficiencies

# $B^0_{(s)} \to K^0_S h^+ h^-$ branching fractions

[arXiv:1707.01665 , to appear in JHEP]




- Background subtracted

Branching fractions measured relative to $B^0 \to K^0_S\pi^+\pi^-$, using the world average value (minus LHCb) of $\mathcal{B}(B^0 \to K^0\pi^+\pi^-) = (4.96 \pm 0.20) \times 10^{-5}$:

$$\begin{aligned}
\mathcal{B}(B^0 \to \overset{(-)}{K}{}^0 K^\pm\pi^\mp) &= (6.1 \pm 0.5 \pm 0.7 \pm 0.3) \times 10^{-6}\,,\\
\mathcal{B}(B^0 \to K^0 K^+ K^-) &= (27.2 \pm 0.9 \pm 1.6 \pm 1.1) \times 10^{-6}\,,\\
\mathcal{B}(B^0_s \to K^0\pi^+\pi^-) &= (9.5 \pm 1.3 \pm 1.5 \pm 0.4) \times 10^{-6}\,,\\
\mathcal{B}(B^0_s \to \overset{(-)}{K}{}^0 K^\pm\pi^\mp) &= (84.3 \pm 3.5 \pm 7.4 \pm 3.4) \times 10^{-6}\,,\\
\mathcal{B}(B^0_s \to K^0 K^+ K^-) &\in [0.4 - 2.5] \times 10^{-6} \text{ at } 90\% \text{ C.L.}\,,
\end{aligned}$$

where the first uncertainty is statistical, the second systematic, and the third due to $\mathcal{B}(B^0 \to K^0\pi^+\pi^-)$. The confidence interval for $B^0_s \to K^0_S K^+ K^-$ is obtained using the Feldman-Cousins method.

# $\overline{B}^0 \to K^0_S \pi^+ \pi^-$ amplitude analysis

[LHCb-PAPER-2017-033, To be submitted to PRL]

- Time-integrated, untagged analysis - first step towards measurements of $\beta_{\mathrm{eff}}$ in a time-dependent analysis
- B-factory measurements found evidence for negative CP-asymmetry in the decay of $\overline{B}^0 \to K^*(892)^-\pi^+$ [arXiv:1105.0125, arXiv:0905.3615, arXiv:0811.3665]
- Selection identical to the branching fraction analysis described previously
- Combinatorial background taken from sideband, $m(K^0_{\mathrm{S}}\pi^+\pi^-) > 5450$ MeV, and dominant cross-feed ($B^0_s \to K^0_{\mathrm{S}}K^{\mp}\pi^{\mp}$) Dalitz-plot distribution taken from data

# $\overline{B}^0 \to K^0_S \pi^+ \pi^-$ time independent

[LHCb-PAPER-2017-033, to be submitted to PRL]

- Amplitude model parameterised in terms of invariant-mass pairs $m^2_{K^0_S\pi^+}$ and $m^2_{K^0_S\pi^-}$ ($s^+$ and $s^-$),

$$\mathcal{A} = \sum_j^N c_j \, F_j \, (s^+, s^-),$$

Form of $F$ given by:

$$F(s^+, s^-) \propto T(s^+, s^-) \,\cdot\, Z(s^+, s^-, L) \,\cdot\, X(s^+, s^-, L)$$

- $\mathrm{T(s^+, s^-)}$: Mass distribution in $m_{K^0_S\pi^\pm}$ or $m_{\pi^+\pi^-}$ (lineshape)
- $\mathrm{Z(s^+, s^-, L)}$: Spin term, resonance spin $L$ (using Zemach tensors) - proportional to Legendre polynomial
- $\mathrm{X(s^+, s^-, L)}$: Centrifugal barrier term (Blatt-Weisskopf)

# $\overline{B}^0 \to K^0_S\pi^+\pi^-$ time independent

[LHCb-PAPER-2017-033, to be submitted to PRL]

- $\mathcal{A}$ built by starting with those contributions identified in the B-factory analyses
- Contributions are added (or removed) depending on the likelihood, goodness of fit, or component magnitude

| Resonance | Model |
|---|---|
| $K^*(892)^-$ | Relativistic Breit–Wigner |
| $(K\pi)_0$ | Model from QCDF (EFKLLM, arXiv:0902.3645) |
| $K_2^*(1430)^-$ | Relativistic Breit–Wigner |
| $K^*(1680)^-$ | Flatté |
| $f_0(500)$ | Relativistic Breit–Wigner |
| $\rho(770)^0$ | Gounaris–Sakurai |
| $f_0(980)$ | Flatté |
| $f_0(1500)$ | Relativistic Breit–Wigner |
| $\chi_{c^0}$ | Relativistic Breit–Wigner |

- Plus a flat non-resonant contribution

# $\overline{B}^0 \to K^0_S\pi^+\pi^-$ CP asymmetries

[LHCb-PAPER-2017-033, to be submitted to PRL]

- For quasi-flavour-specific final states, the CP asymmetry from the isobar coeffcients

$$A_{CP}^{\text{isobar}} = \frac{|\bar{c}_j|^2 - |c_j|^2}{|\bar{c}_j|^2 + |c_j|^2}$$

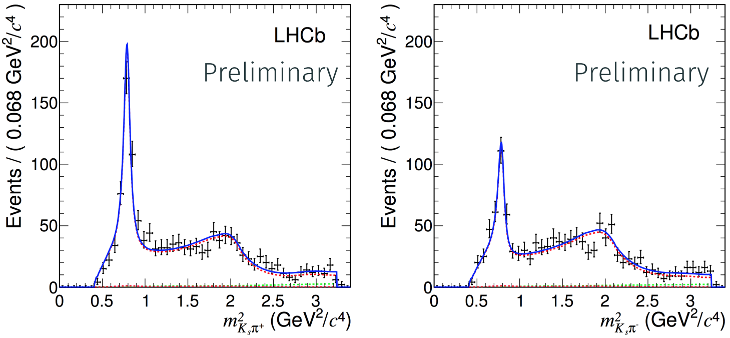
is corrected for the $\overline{B}^0/B^0$ production asymmetry of approximately $-0.35\%$ (and the pion detection asymmetry is consistent with zero).

- Quasi-two-body branching fractions are obtained using the fit fraction of each contribution - the relative intensity if only a single component contributed

$$FF_i = \frac{\int_{\text{DP}} |c_i F_i|^2 ds^+ ds^-}{\int_{\text{DP}} |\sum_j c_j F_j|^2 ds^+ ds^-}.$$

# $\overline{B}^0 \to K^0_S\pi^+\pi^-$ fit projections

[LHCb-PAPER-2017-033, to be submitted to PRL]




- Significant asymmetry in the $K^*(892)^\pm$ region!
- Systematic uncertainties arise from knowledge of the fit yield, the variation of the signal efficiency and background across the Dalitz plot, the fixed model parameters, modelling the S-wave components, and marginal contributions to the amplitude.

- After applying efficiency corrections (same as branching fraction analysis), and correcting for production asymmetry:

$$\boxed{\mathcal{A}_{\rm CP}(\overline{B}^0 \to K^*(892)^-\pi^+) = -0.308 \pm 0.060 \pm 0.011 \pm 0.012}$$

- Approximately $6\sigma$ from zero - first observation of CP violation in this mode

- Also measure $\mathcal{A}_{\rm CP}$ for other decays:

$$\begin{aligned}
\mathcal{A}_{CP}((K\pi)^{*-}_0\pi^+) &= -0.032 \pm 0.047 \pm 0.016 \pm 0.027 \\
\mathcal{A}_{CP}(K^*_2(1430)^-\pi^+) &= -0.29 \pm 0.22 \pm 0.09 \pm 0.03 \\
\mathcal{A}_{CP}(K^*(1680)^-\pi^+) &= -0.07 \pm 0.13 \pm 0.02 \pm 0.03 \\
\mathcal{A}_{CP}(f_0(980)K^0_S) &= 0.28 \pm 0.27 \pm 0.05 \pm 0.14
\end{aligned}$$

where uncertainties are statistical, systematic (experimental) and systematic (DP model)

# $\Lambda_b^0(\Xi_b^0) \to p h^- h^+ h^-$ decays

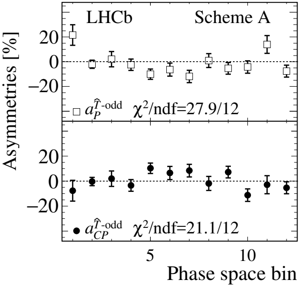
[LHCb-PAPER-2017-034, To be submitted to JHEP]

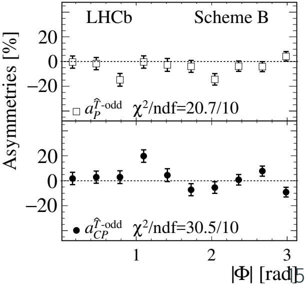
# $\Lambda_b^0(\Xi_b^0) \to ph^-h^+h^-$ decays

[LHCb-PAPER-2017-034, to be submitted to JHEP]

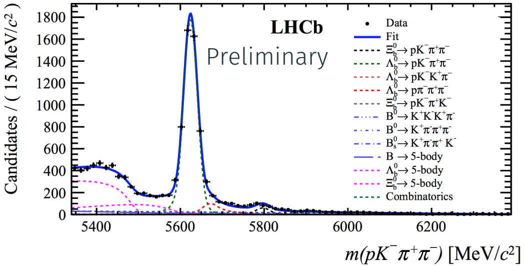
- Tree and loop contributions similar magnitude - potential for large CPV in decay

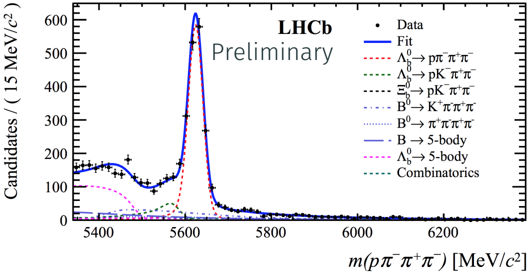
- Previous publication by LHCb on triple-product asymmetries - evidence for CP violation ($3.3\sigma$) in the decay of $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ [arXiv:1609.05216]



- Only use candidates independent of a trigger decision on signal - avoid biasing phase-space
- Simultaneous fit to all final states, constraining $(\pi \leftrightarrow K)$ cross-feed
- $m(\Xi_b^0) - m(\Lambda_b^0)$ constrained to the world-average value

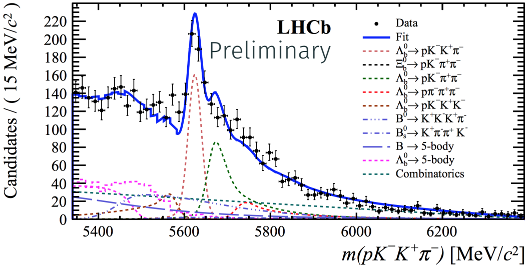


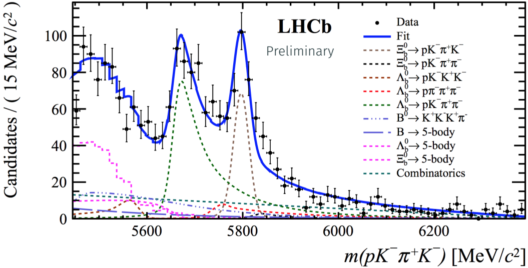



#  $\Lambda_b^0(\Xi_b^0) \to p h^- h^+ h^-$ branching fractions

[LHCb-PAPER-2017-034, to be submitted to JHEP]

- Background contribution from multibody *B* decays estimated by a fit to the spectrum following a proton mass hypothesis swap
- Dominant systematic uncertainty on the branching fractions arises from the variation of the efficiency across the phase-space



# $\Lambda_b^0(\Xi_b^0) \to ph^-h^+h^-$ branching fractions

[LHCb-PAPER-2017-034, to be submitted to JHEP]

Branching fractions are measured relative to $\Lambda_b^0 \to \Lambda_c^+(pK^-\pi^+)\pi^-$,

$$\begin{aligned}
\mathcal{B}(\Lambda_b^0 \to p\pi^-\pi^+\pi^-) &= (1.90 \pm 0.06 \pm 0.10 \pm 0.16 \pm 0.07) \cdot 10^{-5}, \\
\mathcal{B}(\Lambda_b^0 \to pK^-\pi^+\pi^-) &= (4.55 \pm 0.08 \pm 0.20 \pm 0.39 \pm 0.17) \cdot 10^{-5}, \\
\mathcal{B}(\Lambda_b^0 \to pK^-K^+\pi^-) &= (0.37 \pm 0.03 \pm 0.04 \pm 0.03 \pm 0.01) \cdot 10^{-5}, \\
\mathcal{B}(\Lambda_b^0 \to pK^-K^+K^-) &= (1.14 \pm 0.03 \pm 0.07 \pm 0.10 \pm 0.05) \cdot 10^{-5},
\end{aligned}$$

where uncertainties are statistical, systematic, and from the $\Lambda_b^0 \to \Lambda_c^+\pi^-$ and $\Lambda_c^+ \to pK^-\pi^+$ branching fractions. Results for $\Xi_b^0$

$$\begin{aligned}
\mathcal{B}(\Xi_b^0 \to pK^-\pi^+\pi^-) \cdot f_{\Xi_b^0}/f_{\Lambda_b^0} &= (1.72 \pm 0.21 \pm 0.25 \pm 0.15 \pm 0.07) \cdot 10^{-6}, \\
\mathcal{B}(\Xi_b^0 \to pK^-\pi^+K^-) \cdot f_{\Xi_b^0}/f_{\Lambda_b^0} &= (1.56 \pm 0.16 \pm 0.19 \pm 0.13 \pm 0.06) \cdot 10^{-6}, \\
\mathcal{B}(\Xi_b^0 \to pK^-K^+K^-) \cdot f_{\Xi_b^0}/f_{\Lambda_b^0} &\in [0.11\text{--}0.25] \cdot 10^{-6} \text{ at } 90\ \%\ \text{C.L.}
\end{aligned}$$

are a product of the branching fraction and ratio of the production fractions of $\Xi_b^0$ and $\Lambda_b^0$ baryons ($f_{\Xi_b^0/\Lambda_b^0}$). The interval on $\Xi_b^0 \to pK^-K^+K^-$ branching fraction is obtained using the Feldman-Cousins method.

# $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ time-dependent analyses

[LHCb-CONF-2016-018]

# $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ time-dependent analyses [LHCb-CONF-2016-018]

- Time-dependent measurement of CP violation in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ using 3fb$^{-1}$ of data - supersedes 1fb$^{-1}$ LHCb measurement [arXiv:1308.1428]
- Can extract CKM angles $\gamma$ and $\beta_s$ via U-spin symmetry [arXiv:1408.4368]
- For

$$\mathcal{A}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} = \frac{-C_f \cos(\Delta m_{d,s} t) + S_f \sin(\Delta m_{d,s} t)}{\cosh\left(\frac{\Delta\Gamma_{d,s}}{2}t\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_{d,s}}{2}t\right)}$$

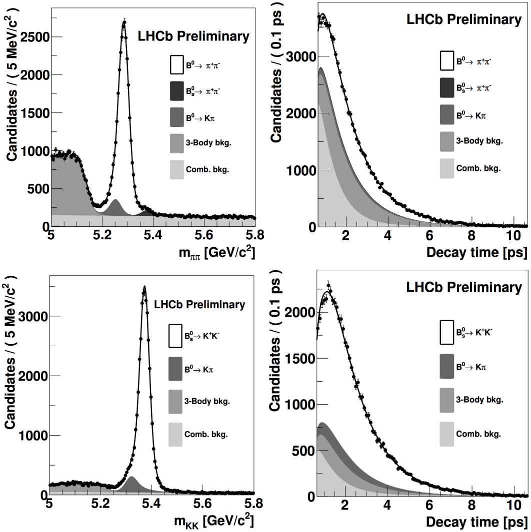
extract parameters corresponding to

$$C_f \equiv \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}, \qquad S_f \equiv \frac{2\mathrm{Im}\lambda_f}{1+|\lambda_f|^2}, \qquad A_f^{\Delta\Gamma} \equiv -\frac{2\mathrm{Re}\lambda_f}{1+|\lambda_f|^2},$$

$$\lambda_f \equiv \frac{q}{p}\frac{\bar{A}_f}{A_f}.$$

# $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ time-dependent analyses [LHCb-CONF-2016-018]

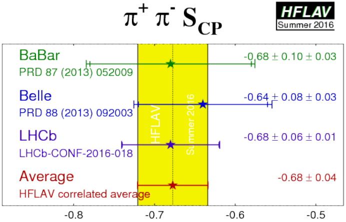
- $N(B^0 \to \pi^+\pi^-) = 28\,652 \pm 226$
- $N(B^0 \to K^+K^-) = 36\,840 \pm 222$
- Flavour tagging calibrated using $B_s^0 \to K^\pm\pi^\mp$ - all final states fitted simultaneously

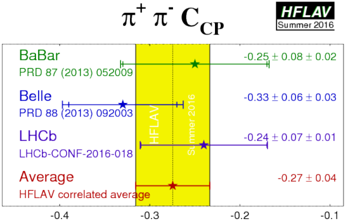


# $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ time-dependent analyses [LHCb-CONF-2016-018]

$$\begin{aligned} C_{\pi^+\pi^-} &= -0.24 \pm 0.07 \pm 0.01, \\ S_{\pi^+\pi^-} &= -0.68 \pm 0.06 \pm 0.01, \\ C_{K^+K^-} &= 0.24 \pm 0.06 \pm 0.02, \\ S_{K^+K^-} &= 0.22 \pm 0.06 \pm 0.02, \\ A^{\Delta\Gamma}_{K^+K^-} &= -0.75 \pm 0.07 \pm 0.11, \end{aligned}$$

- Consistent with B-factory values - most precise value of $S_{\pi^+\pi^-}$
- $(S_{K^+K^-}, C_{K^+K^-})$ differs from $(0, 0)$ at a level of $4.6\sigma$
- Ongoing work to include additional ('same side') flavour taggers, update for Run 2 LHCb data, and measure CKM parameters



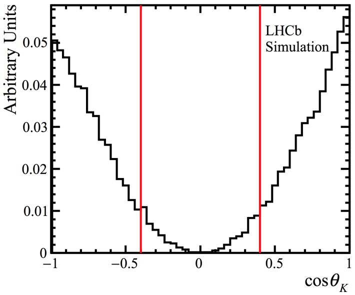
# Search for $B^+ \to D_s^+ K^+ K^-$ decays

[LHCb-PAPER-2017-032, To be submitted to JHEP]

# $B^+ \to D_s^+ K^+ K^-$ decays

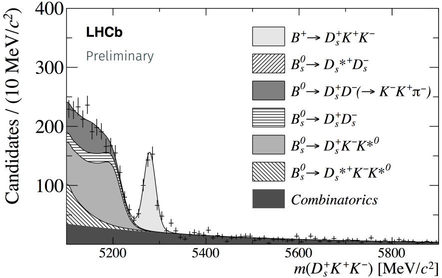
[LHCb-PAPER-2017-032, to be submitted to JHEP]

- $B^+ \to D_s^+ \phi$ proceeds primarily via annihilation diagram in SM - predictions of branching fraction $\mathcal{O}(10^{-7})$
- Additional diagrams contribute in extensions to SM - enhance branching fractions and/or CP asymmetries
- Update previous measurement ($3.0\text{fb}^{-1}$) to $4.7\text{fb}^{-1}$

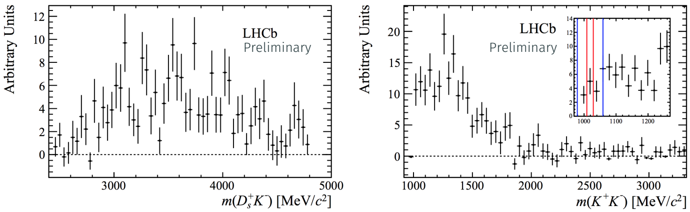



- Selection of $\phi$ enhanced with cut on helicity angle of $|\cos\theta_{\text{hel}}| > 0.4$ - background approximately uniform, efficiency of 82% for signal
- $D_s^+ \to K^+K^-\pi^+$ used for $B^+ \to D_s^+ K^+ K^-$ search, additionally $D_s^+ \to K^+\pi^-\pi^+$ and $D_s^+ \to \pi^+\pi^-\pi^+$ for $B^+ \to D_s^+ \phi$

- Total $B^+ \to D_s^+ K^+ K^-$ yield of $443 \pm 29$ - first observation
- $B^+ \to D_s^+ K^+ K^-$ efficiencies corrected using the background subtracted phase-space distribution, $B^+ \to D_s^+ \phi$ assumed to have no variation




- Dominant systematic uncertainties are from the knowledge of the relative efficiencies (for $B^+ \to D_s^+ K^+ K^-$), and background fit PDFs and the assumption that $B^+ \to D_s^+ K^+ K^-$ proceeds purely via $f_0(980)$ or $a_0(980)$




- Background subtracted and efficiency corrected $m(D_s^+ K^-)$ (left) and $m(K^+K^-)$ (right)
- Branching fraction measurements (normalised to $B^+ \to D_s^+ \overline{D}^0 (K^+K^-)$):

$$\mathcal{B}(B^+ \to D_s^+ K^+ K^-) = (7.1 \pm 0.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

$$\mathcal{B}(B^+ \to D_s^+ \phi) < 4.4\ (4.9) \times 10^{-7}, \text{ at 90(5)\% confidence}$$

- Uncertainties are statistical, systematic, and on the resonance and normalisation branching fractions.

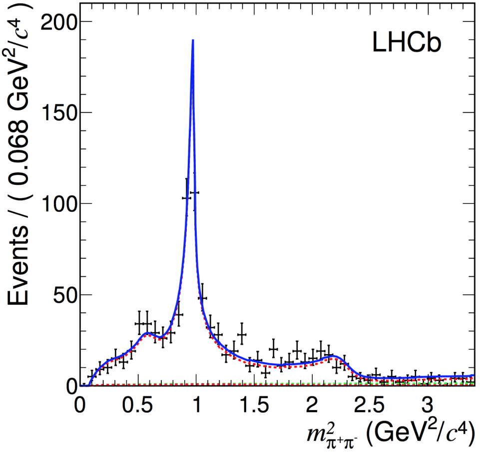
# Summary

# Summary

- Most precise measurements of the $B^0_{(s)} \to K^0_S h^+ h^-$ branching fractions, but are yet to observe $B^0_s \to K^0_S K^+ K^-$
- Untagged, time-integrated amplitude analysis of $\overline{B}^0 \to K^0_S \pi^+ \pi^-$ performed, and CP violation observed for the first time in the decay of $\overline{B}^0 \to K^{*-} \pi^+$ at a level of $6\sigma$
- First observations of many four-body $b$-baryon decay modes, with a large number of candidates - perfect for further investigations of CPV in baryon decays
- Updated time-dependent study of $B^0 \to \pi^+ \pi^-$ and $B^0_s \to K^+ K^-$ decays, with evidence for CPV in $B^0_s \to K^+ K^-$ decays
- First observation of $B^+ \to D^+_s K^+ K^-$, and limit on $\mathcal{B}(B^+ \to D^+_s \phi)$
- Many more results on these and other topics coming soon!

# Backup

# $\overline{B}^0 \to K^0_S \pi^+ \pi^-$



# EFKLLM

$$T(m) = F(m)\left(\frac{c_0}{m^2} + c_1\right)$$

- F(m) form factors
- $c_0$, $c_1$ left free in fit (phase of one fixed here)
- Parameterises the full invariant-mass range

# CPV in $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ decays

With $C_{\hat{\mathrm{T}}} = p_p \cdot (p_{h_1^-} \times p_{h_2^+})$, and $\overline{C}_{\hat{\mathrm{T}}} = p_{\bar{p}} \cdot (p_{h_1^+} \times p_{h_2^-})$:

$$A_{\widehat{T}}(C_{\widehat{T}}) = \frac{N(C_{\widehat{T}} > 0) - N(C_{\widehat{T}} < 0)}{N(C_{\widehat{T}} > 0) + N(C_{\widehat{T}} < 0)},$$
$$\overline{A}_{\widehat{T}}(\overline{C}_{\widehat{T}}) = \frac{\overline{N}(-\overline{C}_{\widehat{T}} > 0) - \overline{N}(-\overline{C}_{\widehat{T}} < 0)}{\overline{N}(-\overline{C}_{\widehat{T}} > 0) + \overline{N}(-\overline{C}_{\widehat{T}} < 0)},$$

$$a_{CP}^{\widehat{T}\text{-odd}} = \frac{1}{2}\left(A_{\widehat{T}} - \overline{A}_{\widehat{T}}\right),$$

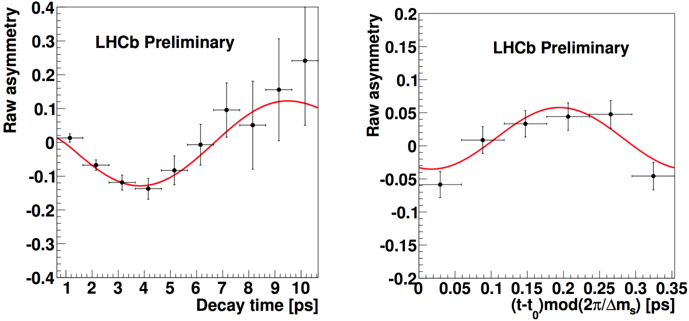
# $\Lambda_b^0(\Xi_b^0) \to ph^-h^+h^-$ decays

- Simultaneous fit yields:

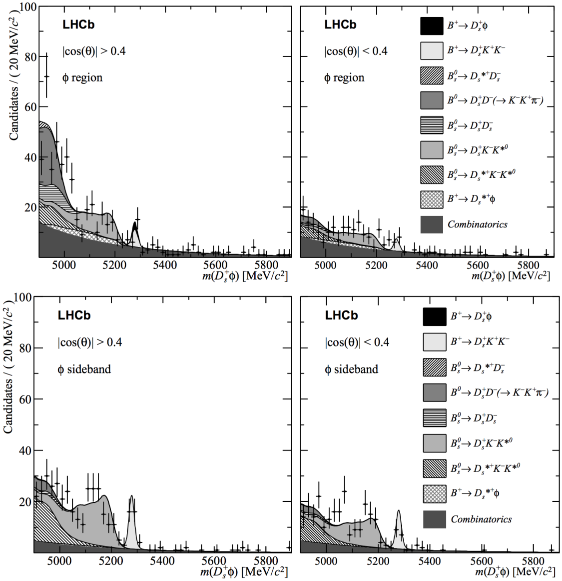
| Decay mode | Signal yield | $S/B$ | $\pm 3\sigma$ range ( MeV/$c^2$) |
|---|---|---|---|
| $\Lambda_b^0 \to p\pi^-\pi^+\pi^-$ | $1809 \pm 48$ | $4.9 \pm 0.3$ | [5573.9, 5674.6] |
| $\Lambda_b^0 \to pK^-\pi^+\pi^-$ | $5193 \pm 76$ | $7.7 \pm 0.4$ | [5574.4, 5674.2] |
| $\Lambda_b^0 \to pK^-K^+\pi^-$ | $444 \pm 30$ | $0.71 \pm 0.06$ | [5577.4, 5671.1] |
| $\Lambda_b^0 \to pK^-K^+K^-$ | $1706 \pm 46$ | $8.1 \pm 0.7$ | [5579.0, 5674.6] |
| $\Xi_b^0 \to pK^-\pi^+\pi^-$ | $183 \pm 22$ | $0.59 \pm 0.09$ | [5747.9, 5846.2] |
| $\Xi_b^0 \to pK^-\pi^+K^-$ | $199 \pm 21$ | $0.8 \pm 0.1$ | [5747.4, 5846.2] |
| $\Xi_b^0 \to pK^-K^+K^-$ | $27 \pm 14$ | $0.14 \pm 0.08$ | [5752.7, 5840.8] |
| $\Lambda_b^0 \to (\Lambda_c^+ \to pK^-\pi^+)\pi^-$ | $16518 \pm 133$ | - | [5573.7, 5674.8] |

# $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ time-dependent analyses

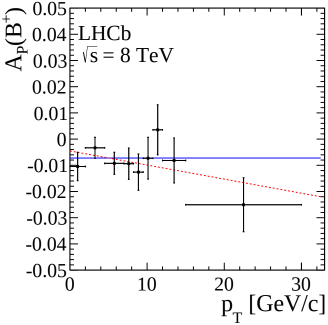
- Time-dependent asymmetry $B^0 \to \pi^+\pi^-$ (left), $B_s^0 \to K^+K^-$ (right):

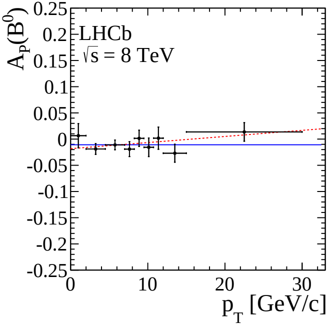


# $B^+ \to D_s^+ K^+ K^-$ fit categories



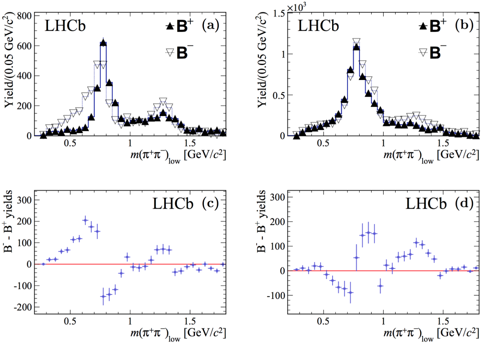
# Production asymmetries, 8TeV



# An aside on S-wave

- Accurate S-wave models very important, e.g., in $B^+ \to \pi^+\pi^+\pi^-$ Dalitz-plot (from arXiv:1408.5373)
- Characteristic of CPV in interference between S and P-wave




- S-wave can be modelled using different approaches as cross-check (e.g, K-matrix, isobar model, model independent, …)
- Experimenting with better motivated S-wave descriptions (e.g., unitarity conserving K-matrix models)