Dalitz-plot analyses of three-body charmless decays and search for CPV in *b*-baryon decays

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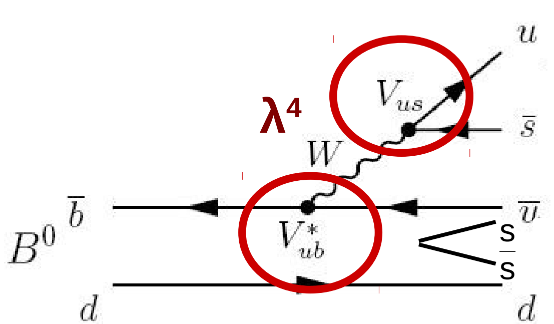
On behalf of the LHCb collaboration
FPCP, Hyderabad, 15/07/2018

Outline

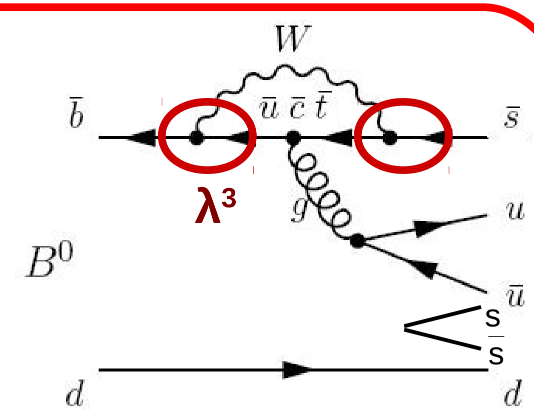
- Motivations
- The LHCb detector at LHC
- Results on charmless decays from LHCb Run I analysis
  - Update of $B_{d,s} \rightarrow K_S h^+ h'^-$ branching fractions. [JHEP. (2017) 2017: 27]
  - Amplitude analysis of $B_d \rightarrow K_S \pi^+ \pi^-$ decays and first observation of CP asymmetry in $B^0 \rightarrow K^*(892)^+ \pi^-$. [PRL. 120, 261801 (2018)]
  - Search for CP violation using tripleproduct asymmetries in $\Lambda_b \rightarrow pK^- \pi^+ \pi^-$, $\Lambda_b \rightarrow pK^- K^+ K^-$ and $\Xi_b \rightarrow pK^- K^- \pi^+$ decays. [arxiv:1805.03941]
  - Search for CP violation in $\Lambda_b \rightarrow p\pi^-$ and $\Lambda_b \rightarrow pK^-$ decays. [LHCB-PAPER-2018-025-002]
- Conclusion and prospects

Introduction

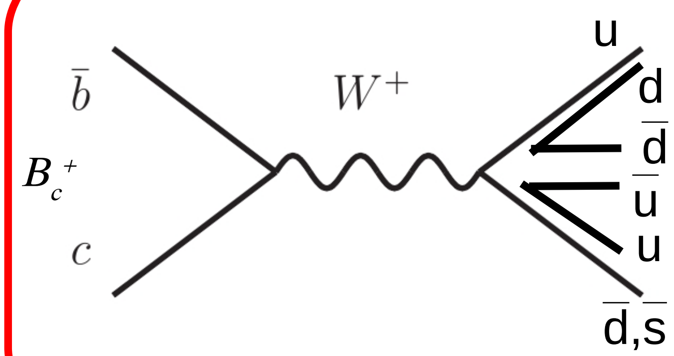
- Charmless *b*-hadron decays proceed through various processes.



b→u tree



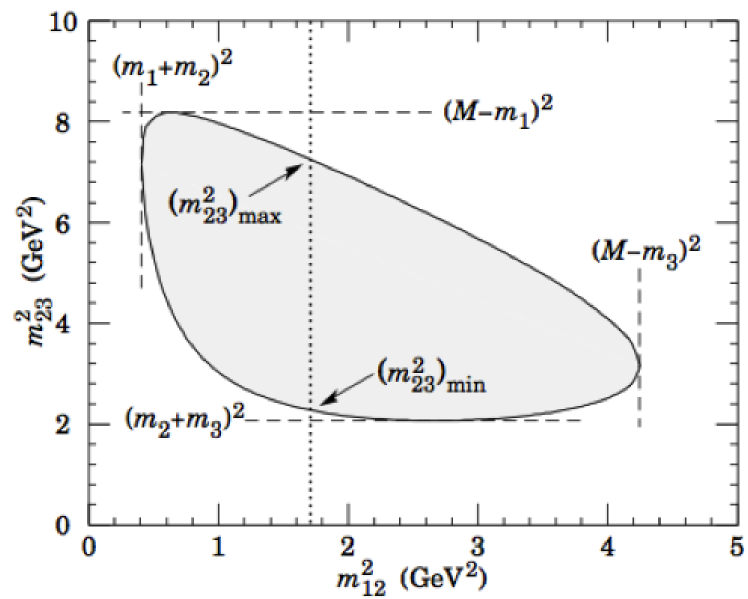
b→d,s penguin



annihilation

can interfere → CP violation

- BSM particles can contribute inside of loops or instead of W+.
- Three-body decays allow access to phases between quasi two-body decays (Q2B) using
  - angular analyses;
  - Dalitz-plot analyses.
  - No trigonometric ambiguity!
- CP violation in baryons has only recently been observed
  - Nature Physics 13, 391-396 (2017)



Current status of charmless *b*-decays

- Many channels not yet observed
  - Suppressed decays (BR < 10^{-5})
  - Includes decays of B_s, Λ_b, *b*-baryons etc.→not accessible by *B* factories.

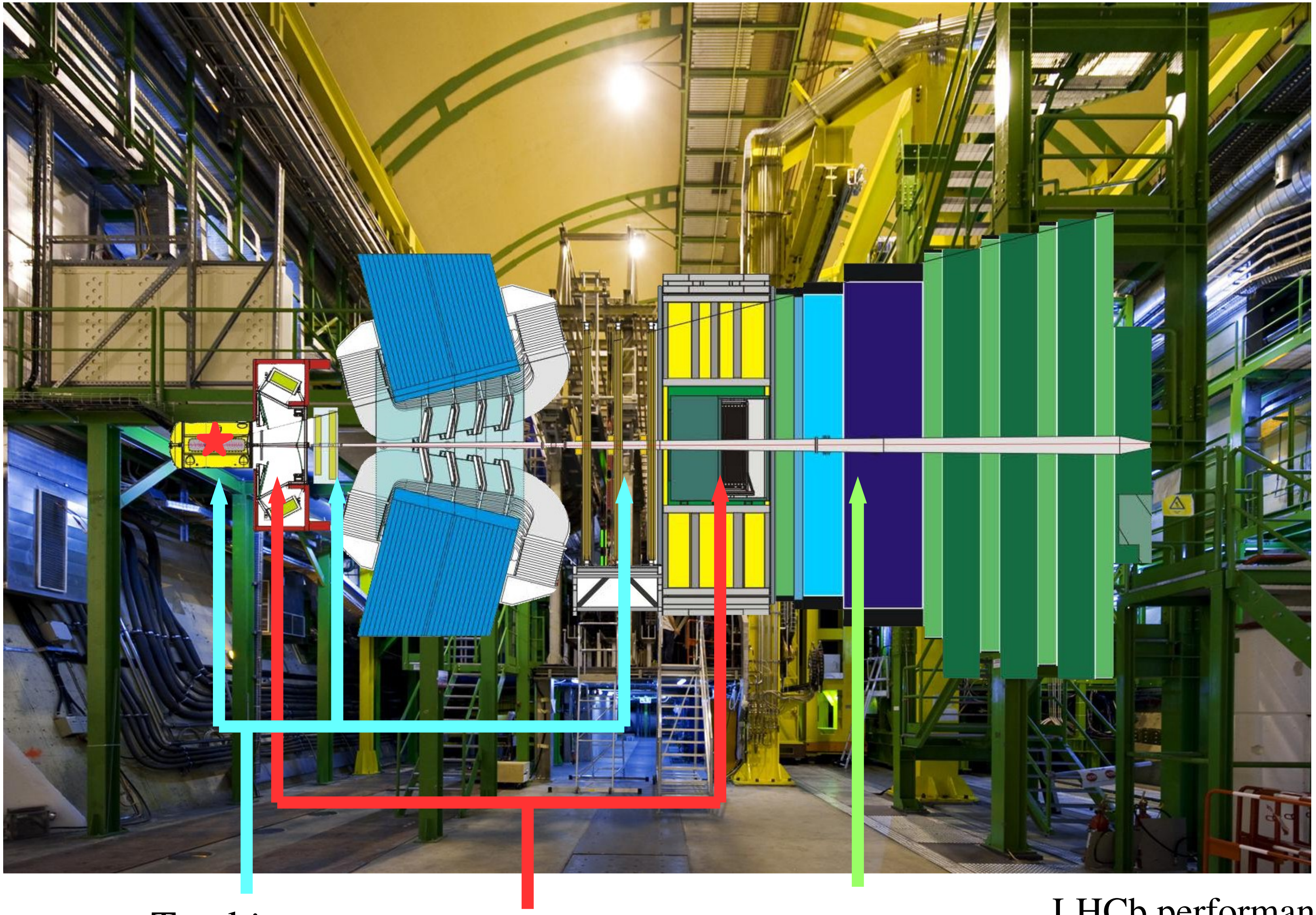
- Final-state particles: protons, kaons, pions, and sometimes photons from π^0 decays.
  - Decays involving π^0 are more difficult, but lots of effort in that area.

- For most decays, programme in two steps:

  1. Observe modes for the first time and extract branching fractions.

  2. Perform angular, Dalitz-plot analyses to access physics observables , e.g. **phases, CPV observables**.

The LHCb detector



Tracking
$\Delta p/p$ = 0.5-1%

PID
95% K eff
For 5% $\pi \rightarrow K$ misID

Calorimetry
ECAL resolution:
1 % + 10 %/ $\sqrt{E[GeV]}$

LHCb performance paper
arXiv:1412.6352

Results on charmless decays from LHCb Run I analysis ($3fb^{-1}$)

Update of $B_{d,s} \to K_S h^+ h'^-$ branching fractions

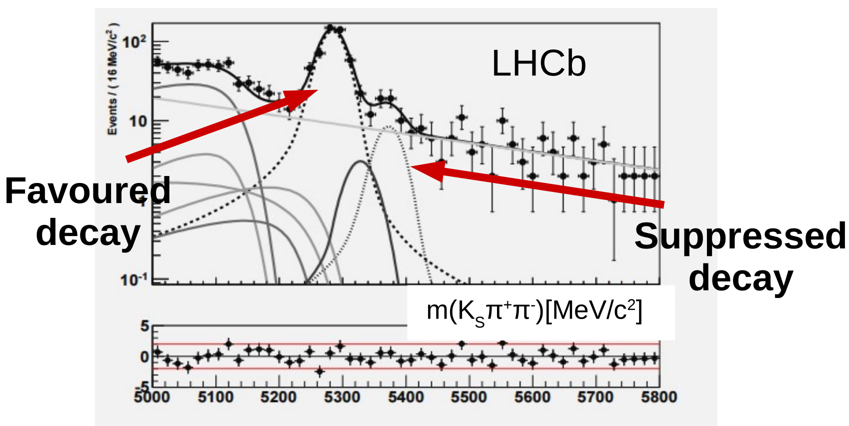
[JHEP. (2017) 2017: 27]

- $B_{d,s} \to K_s h^+ h^{-\prime}$, with h, h' = π,K → 8 decays.

$B_d \to K_S \pi^+ \pi^-$	$B_d \to K_S K^+ \pi^-$	$B_d \to K_S K^- \pi^+$	$B_d \to K_S K^+ K^-$
$B_s \to K_S \pi^+ \pi^-$	$B_s \to K_S K^+ \pi^-$	$B_s \to K_S K^- \pi^+$	$B_s \to K_S K^+ K^-$

Green: observed;
Red: not observed;
▭ : favoured decay (see below).

Previous LHCb analysis ($1fb^{-1}$)
[JHEP 10 (2013) 143]



- Observed $B_s \to K_S \pi^+ \pi^-$.
- Confirmed $B_d \to K_S K^\pm \pi^\pm$.
- Observed $B_s \to K_S K^\pm \pi^\pm$.

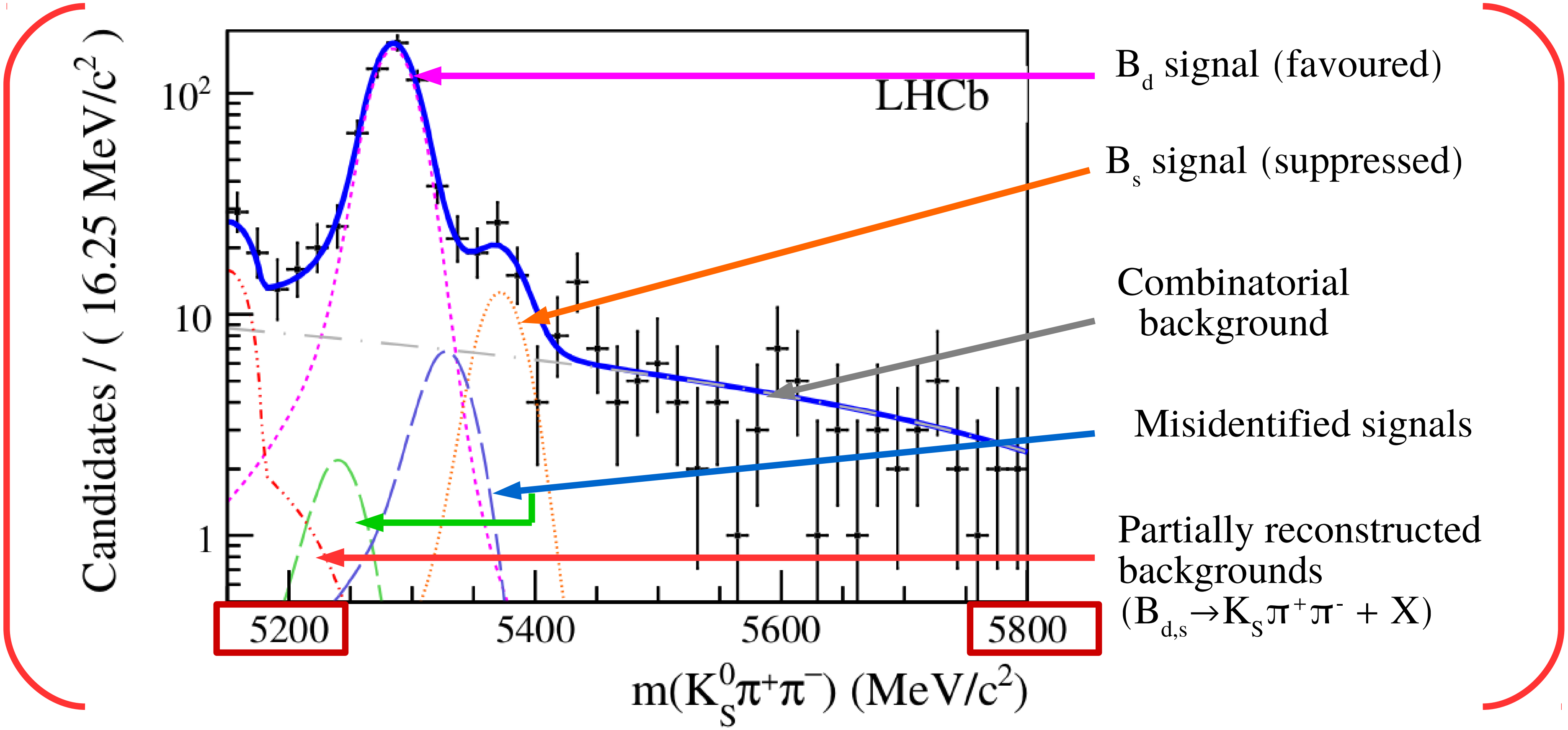
- Goals of the LHCb analysis using $3fb^{-1}$:
  - update measurement of branching fractions;
  - search for $B_s \to K_S K^+ K^-$;
  - prepare Dalitz-plot analyses of all modes.
- Dataset divided into:
  - 4 final states;
  - 2 K_S reconstruction categories (Long-Long, Downstream-Downstream);
  - 3 data-taking periods.

  → 24 invariant-mass distributions

Update of $B_{d,s} \to K_S h^+ h'^-$ branching fractions

[JHEP. (2017) 2017: 27]

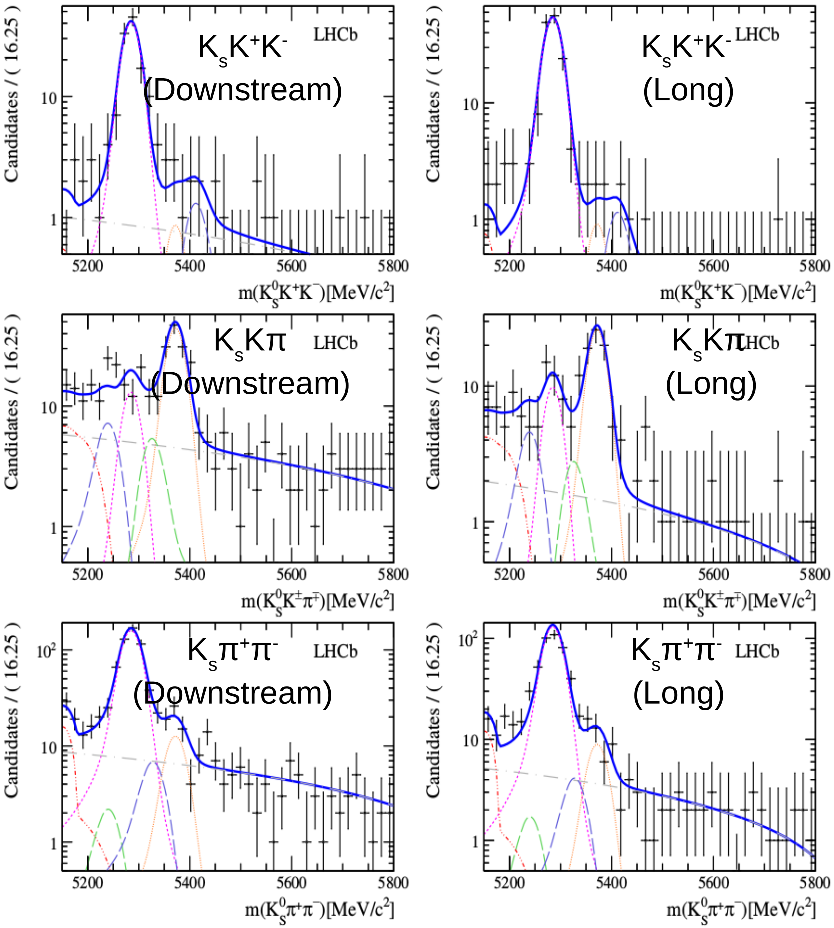
24 x



- Shapes taken from Monte-Carlo, except for combinatorial background.
- B_d and B_s masses and widths fit in data.
- Fast Monte-Carlo developed for partially reconstructed backgrounds modeling.
- Gaussian constraints on misidentified signals and partially recontructed backgrounds yields.

Update of $B_{d,s} \to K_S h^+ h'^-$ branching fractions

[JHEP. (2017) 2017: 27]



$$\frac{\mathcal{B}(B^0_{d,s} \to K^0_S h^+ h'^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = \frac{f_{d,s}}{f_d} \frac{N^{\rm corr}_{B^0_{d,s}\to K^0_S h^+ h'^-}}{N^{\rm corr}_{B^0\to K^0_S \pi^+\pi^-}}.$$

$$N^{\rm corr}_{B^0_{d,s}\to K^0_S h^+ h'^-} = \epsilon^{\rm tot} N_{B^0_{d,s}\to K^0_S h^+ h'^-},$$

$$\frac{\mathcal{B}(B^0 \to K^0_S K^\pm \pi^\mp)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.123 \pm 0.009\ ({\rm stat.})\ \pm 0.015\ ({\rm syst.})\,,$$

$$\frac{\mathcal{B}(B^0 \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.549 \pm 0.018\ ({\rm stat.})\ \pm 0.033\ ({\rm syst.})\,,$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S \pi^+ \pi^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.191 \pm 0.027\ ({\rm stat.})\ \pm 0.031\ ({\rm syst.})\ \pm 0.011\ (f_s/f_d)\,,$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^\pm \pi^\mp)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 1.70\ \pm 0.07\ ({\rm stat.})\ \pm 0.11\ ({\rm syst.})\ \pm 0.10\ (f_s/f_d)\,,$$

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} = 0.026 \pm 0.011\ ({\rm stat.})\ \pm 0.007\ ({\rm syst.})\ \pm 0.002\ (f_s/f_d)\,,$$

Compatible with previous measurements
Dalitz-plot analyses underway.

$B_s \to K_S K^+ K^-$: 2.5σ significance.

$$\frac{\mathcal{B}(B^0_s \to K^0_S K^+ K^-)}{\mathcal{B}(B^0 \to K^0_S \pi^+\pi^-)} \in [0.008 - 0.051] \text{ at } 90\% \text{ C.L.}$$

Amplitude analysis of $B^0 \to K_S \pi^+ \pi^-$

PRL. 120, 261801 (2018)

- Possibly related to the "Kπ" puzzle (difference between A_{CP} in $\overline{B} \to K^- \pi^+$ and $B^- \to K^- \pi^0$).
  Eur. Phys. J. C51 (2007) 55, Phys.Lett. B675 (2009) 59, Phys. Rev.D83 (2011) 034023, Phys. Lett. B682 (2009) 74
- Current statistics do not allow to use flavour tagging (power ~ 5% in LHCb).
- Analysis is time-integrated → amplitude is an incoherent sum of B and $\overline{B}$.

$$\mathcal{P}(s_+, s_-) = \frac{|\mathcal{A}(s_+, s_-)|^2 + |\overline{\mathcal{A}}(s_+, s_-)|^2}{\iint_{\mathrm{DP}} \left(|\mathcal{A}(s_+, s_-)|^2 + |\overline{\mathcal{A}}(s_+, s_-)|^2\right) \mathrm{d}s_+ \mathrm{d}s_-}, \quad \mathcal{A} = \sum_{j=1}^{N} c_j F_j(s_+, s_-), \quad \overline{\mathcal{A}} = \sum_{j=1}^{N} \overline{c}_j \overline{F}_j(s_+, s_-),$$

- Presence of flavour-specific resonances → possible to measure direct CP asymmetries:

$$\mathcal{A}_{CP} = \mathcal{A}_{\mathrm{raw}} - \mathcal{A}_{\Delta}$$

$$\mathcal{A}_{\mathrm{raw}} = \frac{|\overline{c}_j|^2 - |c_j|^2}{|\overline{c}_j|^2 + |c_j|^2}. \qquad \mathcal{A}_{\Delta} = A_P(B^0) + A_D(\pi)$$

Resonance	Parameters	Lineshape
$K^*(892)^-$	$m_0 = 891.66 \pm 0.26$ $\Gamma_0 = 50.8 \pm 0.9$	RBW
$(K\pi)_0^-$	$\mathcal{R}e(\lambda_0) = 0.204 \pm 0.103$ $\mathcal{I}m(\lambda_0) = 0$ $\mathcal{R}e(\lambda_1) = 1$ $\mathcal{I}m(\lambda_1) = 0$	EFKLLM [1]
$K_2^*(1430)^-$	$m_0 = 1425.6 \pm 1.5$ $\Gamma_0 = 98.5 \pm 2.7$	RBW
$K^*(1680)^-$	$m_0 = 1717 \pm 27$ $\Gamma_0 = 332 \pm 110$	Flatté [2]
$f_0(500)$	$m_0 = 513 \pm 32$ $\Gamma_0 = 335 \pm 67$	RBW
$\rho(770)^0$	$m_0 = 775.26 \pm 0.25$ $\Gamma_0 = 149.8 \pm 0.8$	GS [3]
$f_0(980)$	$m_0 = 965 \pm 10$ $g_\pi = 0.165 \pm 0.025$ GeV $g_K = 0.695 \pm 0.119$ GeV	Flatté
$f_0(1500)$	$m_0 = 1505 \pm 6$ $\Gamma_0 = 109 \pm 7$	RBW
χ_{c0}	$m_0 = 3414.75 \pm 0.31$ $\Gamma_0 = 10.5 \pm 0.6$	RBW
Nonresonant (NR)		Phase space

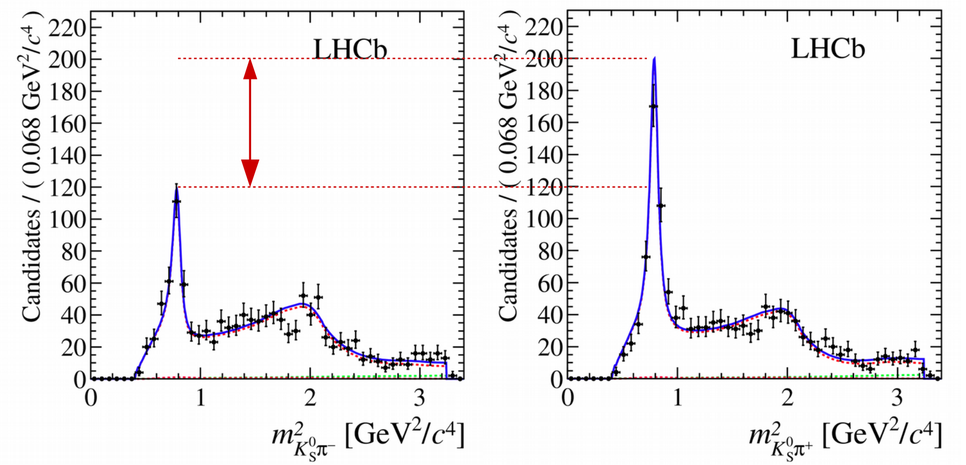
- Baseline model inspired by previous BaBar and Belle analyses, educated by add/remove algorithm.
  [Phys. Rev. D79 (2009) 072004, Phys. Rev. D80 (2009) 112001]

[1]: Phys. Rev. D79 (2009) 094005, [2]: Phys. Lett. B63 (1976) 224,
[3]: Phys. Rev. Lett. 21 (1968) 244.

Amplitude analysis of $B^0 \to K_S\pi^+\pi^-$

PRL. 120, 261801 (2018)

This is CP violation!



- Direct CP violation is already apparent in the $m^2(K_S\pi^+)$ and $m^2(K_S\pi^-)$ projections.
- Resonant structure is modelled and fit fractions extracted.
- Critical role of the $(K\pi)$ S-wave → EFFKLM modelisation.

		Stat.	Syst.	Model.
$\mathcal{F}(K^*(892)^-\pi^+)$	$= 9.43$	± 0.40	± 0.33	± 0.34 %,
$\mathcal{F}((K\pi)^-_0\pi^+)$	$= 32.7$	± 1.4	± 1.5	± 1.1 %,
$\mathcal{F}(K^*_2(1430)^-\pi^+)$	$= 2.45$	$^{+0.10}_{-0.08}$	± 0.14	± 0.12 %,
$\mathcal{F}(K^*(1680)^-\pi^+)$	$= 7.34$	± 0.30	± 0.31	± 0.06 %,
$\mathcal{F}(f_0(980)K^0_S)$	$= 18.6$	± 0.8	± 0.7	± 1.2 %,
$\mathcal{F}(\rho(770)^0K^0_S)$	$= 3.8$	$^{+1.1}_{-1.6}$	± 0.7	± 0.4 %,
$\mathcal{F}(f_0(500)K^0_S)$	$= 0.32$	$^{+0.40}_{-0.08}$	± 0.19	± 0.23 %,
$\mathcal{F}(f_0(1500)K^0_S)$	$= 2.60$	± 0.54	± 1.28	± 0.60 %,
$\mathcal{F}(\chi_{c0}K^0_S)$	$= 2.23$	$^{+0.40}_{-0.32}$	± 0.22	± 0.13 %,
$\mathcal{F}(K^0_S\pi^+\pi^-)^{\rm NR}$	$= 24.3$	± 1.3	± 3.7	± 4.5 %,

		Stat.	Syst.	Model.
$\mathcal{A}_{CP}(K^*(892)^-\pi^+)$	$= -0.308$	± 0.060	± 0.011	± 0.012,
$\mathcal{A}_{CP}((K\pi)^-_0\pi^+)$	$= -0.032$	± 0.047	± 0.016	± 0.027,
$\mathcal{A}_{CP}(K^*_2(1430)^-\pi^+)$	$= -0.29$	± 0.22	± 0.09	± 0.03,
$\mathcal{A}_{CP}(K^*(1680)^-\pi^+)$	$= -0.07$	± 0.13	± 0.02	± 0.03,
$\mathcal{A}_{CP}(f_0(980)K^0_S)$	$= 0.28$	± 0.27	± 0.05	± 0.14,

6σ significant CP violation.
Compatible with current measurements, with similar precision

Search for CP violation using triple-product asymmetries in $\Lambda_b \to pK^-K^+K^-$, $pK^-\pi^+\pi^-$ and $\Xi_b \to pK^-K^-\pi^+$ decays

[arxiv:1805.03941]

- Dominated by a $b \to us\bar{u}$ tree and a $b \to su\bar{u}$ penguin. Relative weak phase dominated by the angle γ.
- First evidence for CP violation in baryons in the $\Lambda_b \to p\pi^-\pi^+\pi^-$ decay mode. [Nature Physics 13, 391-396 (2017)]
- CP-violation effects could be enhanced by the rich resonant structure of these decays.
- Triple products in the final states defined as $C_{\hat{T}} = \vec{p}_p \cdot (\vec{p}_{h_1} \times \vec{p}_{h_2})$ (h_1 is the K^- (with the largest momentum if need to disambiguate), and h_2 the positively charged pion or kaon).
- The motion-reversal operator $\overline{T}$ reverses the spins and momenta of particles. Used to define asymmetries that are (largely) insensitive to production and detection asymmetries:

P- and $\overline{T}$-odd:

$$A_{\hat{T}} = \frac{N(C_{\hat{T}} > 0) - N(C_{\hat{T}} < 0)}{N(C_{\hat{T}} > 0) + N(C_{\hat{T}} < 0)},$$

$$\bar{A}_{\hat{T}} = \frac{\bar{N}(-\bar{C}_{\hat{T}} > 0) - \bar{N}(-\bar{C}_{\hat{T}} < 0)}{\bar{N}(-\bar{C}_{\hat{T}} > 0) + \bar{N}(-\bar{C}_{\hat{T}} < 0)},$$

$$a_P^{\hat{T}\text{-odd}} = \frac{1}{2}\left(A_{\hat{T}} + \bar{A}_{\hat{T}}\right),$$ P-violating

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

Complementary with "usual" A_{CP} observable (ϕ': weak phase, δ': strong phase):

$$A_{\hat{T}} \propto \sin(\delta' + \phi')$$

$$\bar{A}_{\hat{T}} \propto \sin(\delta' - \phi')$$

$$a_{CP}^{\hat{T}\text{-odd}} \propto \sin\phi' \cos\delta'$$

$$\mathcal{A}_{CP} = \frac{N(\Lambda_b^0, \Xi_b^0 \to f) - N(\bar{\Lambda}_b^0, \bar{\Xi}_b^0 \to \bar{f})}{N(\Lambda_b^0, \Xi_b^0 \to f) + N(\bar{\Lambda}_b^0, \bar{\Xi}_b^0 \to \bar{f})} \propto \sin\phi \sin\delta$$

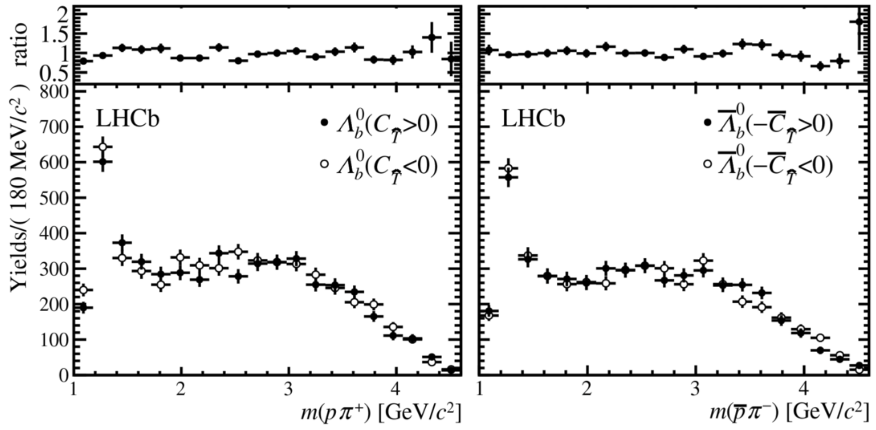
Search for CP violation using triple-product asymmetries in $\Lambda_b \to pK^-K^+K^-$, $pK^-\pi^+\pi^-$ and $\Xi_b \to pK^-K^-\pi^+$ decays

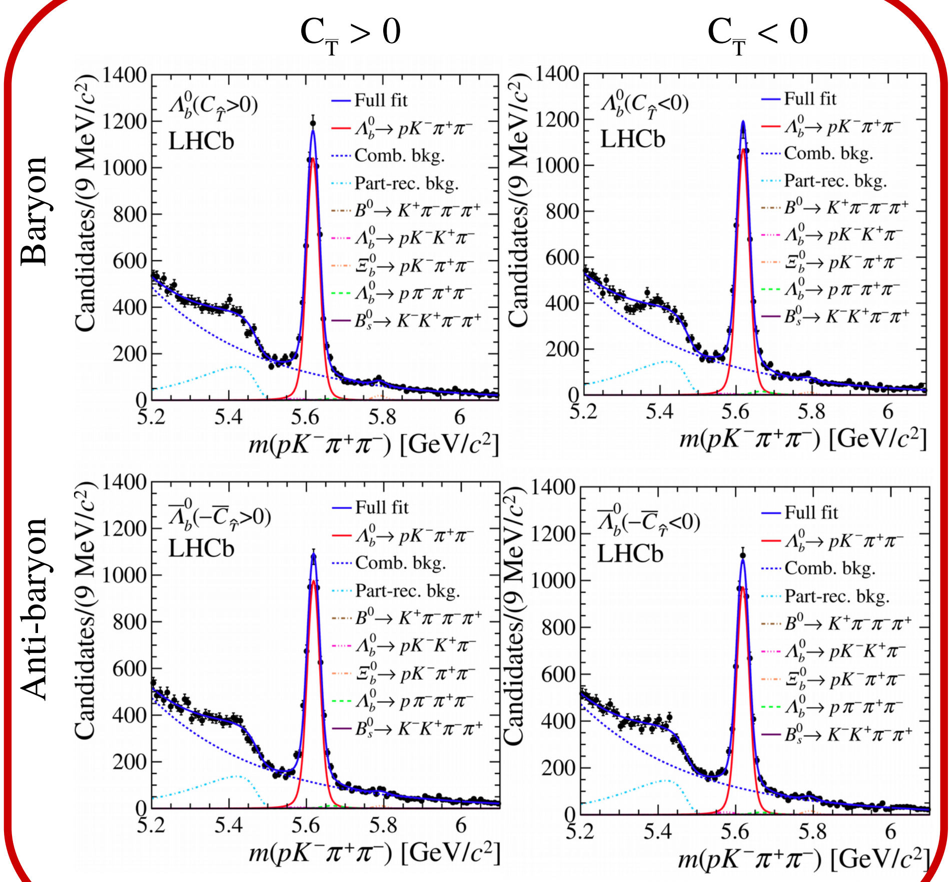
[arxiv:1805.03941]

- Selection fully optimised on data.
- Numbers of events extracted from fits.
- First observation of $\Lambda_b \to pK^-(\chi_{c0}(1P) \to K^+K^-)$ and $\Lambda_b \to pK^-(\chi_{c0}(1P) \to \pi^+\pi^-)$ decays.
- Phase-space integrated asymmetries:

	$\Lambda_b^0 \to pK^-\pi^+\pi^-$	$\Lambda_b^0 \to pK^-K^+K^-$	$\Xi_b^0 \to pK^-K^-\pi^+$
$a_P^{\widehat{T}\text{-odd}}$ (%)	$-0.60 \pm 0.84 \pm 0.31$	$-1.56 \pm 1.51 \pm 0.32$	$-3.04 \pm 5.19 \pm 0.36$
$a_{CP}^{\widehat{T}\text{-odd}}$ (%)	$-0.81 \pm 0.84 \pm 0.31$	$1.12 \pm 1.51 \pm 0.32$	$-3.58 \pm 5.19 \pm 0.36$

  - Consistent with no P or CP violation.
- Phase space divided in bins.





No CP violation observed, either integrated or in regions of phase space
Uncertainties are dominated by statistics

Search for CP violation in $\Lambda_b \to p\pi^-$ and $\Lambda_b \to pK^-$ decays

[LHCB-PAPER-2018-025-002]

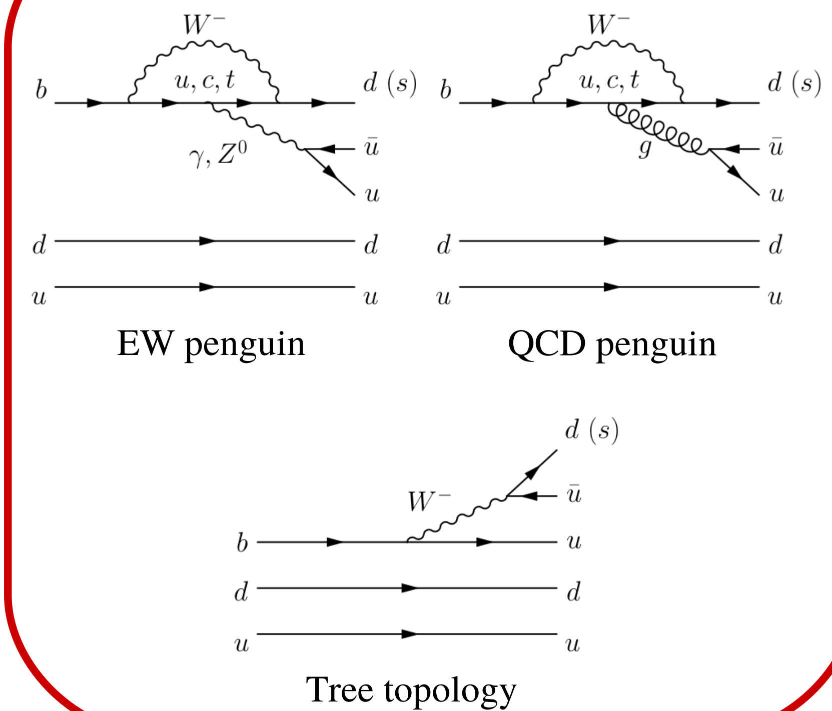
- Theoretical models predict a CP violation in these decays from %-level to ~30% [Phys. Rev. D91(2015) 116007, Phys. Rev. D58 (1998) 094009, Phys. Rev. D80 (2009) 034011]
- Previous result by CDF compatible with 0, with a 8-9% uncertainty [Phys. Rev. Lett. 113 (2014) 242001].
- Analysis strategy: measure raw CP asymmetries

$$A_{\text{raw}}(pK^-) = \frac{N(\Lambda_b^0 \to pK^-) - N(\overline{\Lambda}_b^0 \to \overline{p}K^+)}{N(\Lambda_b^0 \to pK^-) + N(\overline{\Lambda}_b^0 \to \overline{p}K^+)},$$

$$A_{\text{raw}}(p\pi^-) = \frac{N(\Lambda_b^0 \to p\pi^-) - N(\overline{\Lambda}_b^0 \to \overline{p}\pi^+)}{N(\Lambda_b^0 \to p\pi^-) + N(\overline{\Lambda}_b^0 \to \overline{p}\pi^+)},$$

and relate them to CP asymmetries through

Dominant topologies

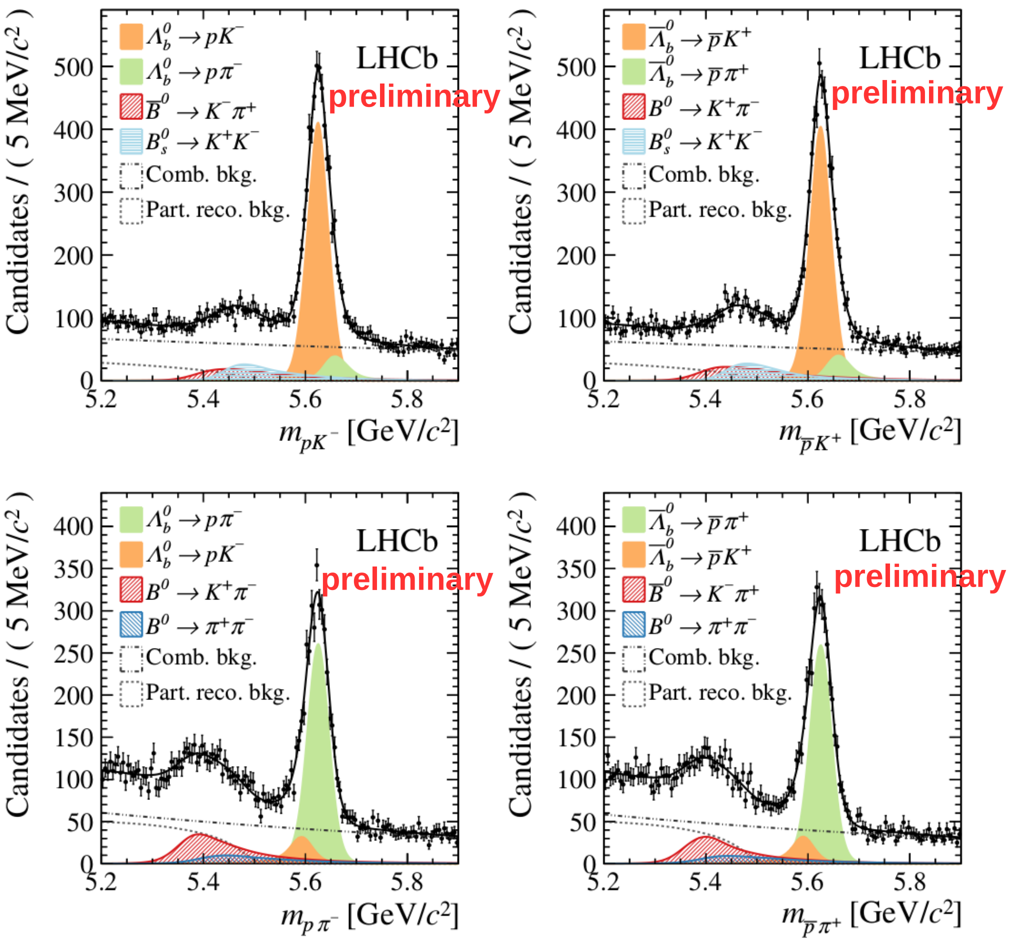


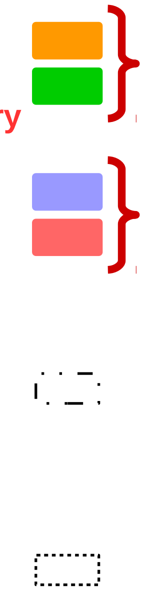
$$\begin{aligned}
A_{CP}(pK^-) &= A_{\text{raw}}(pK^-) - A_{\text{D}}(p) - A_{\text{D}}(K^-) \\
&- A_{\text{PID}}(pK^-) - A_{\text{P}}(\Lambda_b^0) - A_{\text{trigger}}(pK^-), \\
A_{CP}(p\pi^-) &= A_{\text{raw}}(p\pi^-) - A_{\text{D}}(p) - A_{\text{D}}(\pi^-) \\
&- A_{\text{PID}}(p\pi^-) - A_{\text{P}}(\Lambda_b^0) - A_{\text{trigger}}(p\pi^-),
\end{aligned}$$

Search for CP violation in $\Lambda_b \to p\pi^-$ and $\Lambda_b \to pK^-$ decays

[LHCB-PAPER-2018-025-002]

- Large possible contamination from $B^0_{(s)} \to K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$ and K^+K^- (crossfeeds).
- Yields are extracted from simultaneous extended maximum likelihood fits to invariant-mass distributions in the $pK^{+/-}$ and $p\pi^{+/-}$ for the signal, and $K^+\pi^-$, $K^-\pi^+$, $\pi^+\pi^-$ and K^+K^-.
- Crossfeed yields fixed to values in the fit to corresponding final-state hypothesis, multiplied by an efficiency ratio





Signals. Double Gaussian convolved with power law (radiative losses).

Crossfeeds. Yields are extracted from fits to corresponding final state, multiplied by efficiency ratio.

Partially reconstructed backgrounds (three-body decays of which a particle is not reconstructed). Modelled with an ARGUS convolved with the same two Gaussian as in the signal.

Combinatorial backgrounds (random association of unrelated tracks). Modelled with exponential functions.

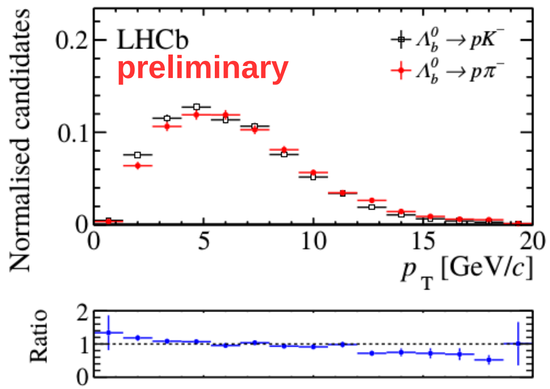
S_{pK^-}		$S_{p\pi^-}$	
$A_{\rm raw}^{pK^-}$ [%]	1.0 ± 1.3	$A_{\rm raw}^{p\pi^-}$ [%]	0.5 ± 1.7
$N_{\rm sig}^{pK^-}$	$8\,847 \pm 125$	$N_{\rm sig}^{p\pi^-}$	$6\,026 \pm 105$

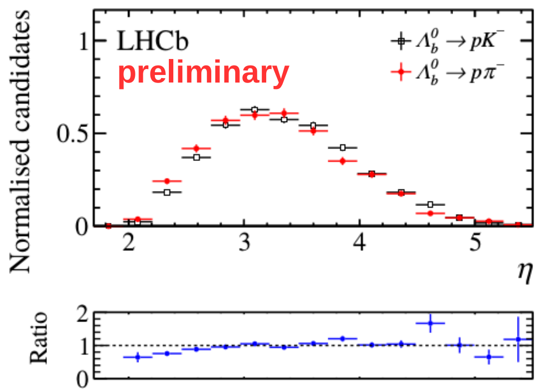
preliminary

Search for CP violation in $\Lambda_b \to p\pi^-$ and $\Lambda_b \to pK^-$ decays

[LHCB-PAPER-2018-025-002]

- K detection asymmetry: from $D^+ \to K^-\pi^+\pi^+$ and $D^+ \to \overline{K}{}^0\pi^+$ (as in JHEP 07 (2014) 041).
- π detection asymmetry: from $D^{*+} \to \pi^+ D^0(\to K^-\pi^+\pi^-\pi^+)$ (as in Phys. Lett. B713 (2012) 186).
- Proton detection asymmetry: simulated events folded with momentum distributions.
- PID asymmetries: reference samples + Monte-Carlo.
- Trigger asymmetries: from $B^0 \to K^-\pi^+$ samples, studying the charge asymmetry for hardware and software decisions.
- Integrated production asymmetries: signal momentum distributions convolved with values from Phys. Lett. B774 (2017) 139.





Systematic uncertainty	$A_{CP}^{pK^-}$ [%]	$A_{CP}^{p\pi^-}$ [%]
Kaon or pion detection asymmetry	0.23	0.11
Proton detection asymmetry	0.67	0.67
PID asymmetry	0.74	0.73
Λ_b^0 production asymmetry	1.40	1.40
Trigger asymmetry	0.53	0.55
Signal model	0.02	0.02
Background model	0.23	0.47
PID efficiencies	0.57	0.74
Total	1.91	2.00

preliminary

Stat. Syst.

$$A_{CP}^{pK^-} = -0.020 \pm 0.013 \pm 0.019,$$
$$A_{CP}^{p\pi^-} = -0.035 \pm 0.017 \pm 0.020,$$

Stat. Syst.

$$\Delta A_{CP} = 0.014 \pm 0.021 \pm 0.013,$$

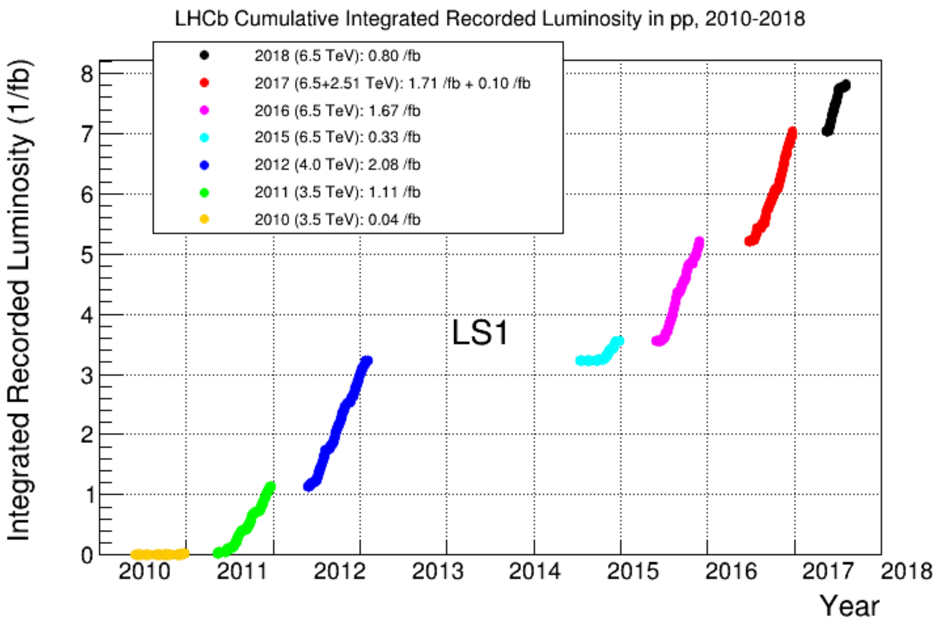
preliminary

No CPV observed, with greatly improved precision

Conclusion and prospects

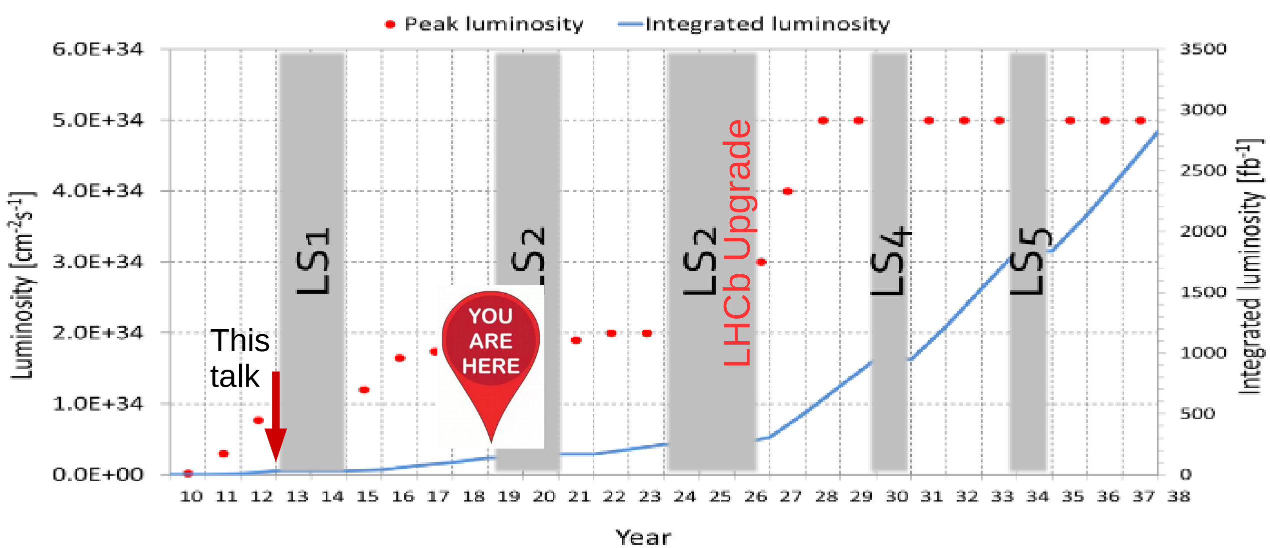
Conclusion and prospects

- All presented results use only data from Run I of the LHC → 3fb^{-1} at centre-of-mass energy of 7 and 8 TeV.



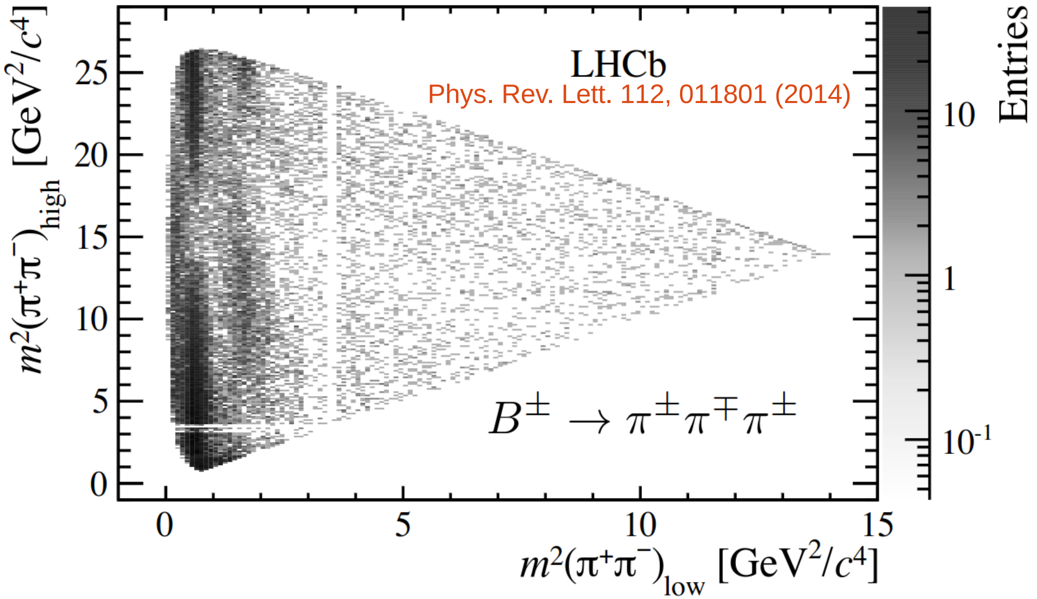
- Run 2 aims at adding 5 fb^{-1} at 13 TeV → more than four times as much data as in Run I.
- All presented analyses are (mostly) dominated by statistical uncertainties.
- Upgrade of all subsystems planned after 2018.

Expected LHC luminosity delivery. [2016 J. Phys.: Conf. Ser.706 022002]



Conclusion and prospects

- New channels observed → physics programme of (three-body) charmless decays is expanding.
- Wealth of different channels:
  - Initial hadron: baryon, B^0, B_s, B_c^+
  - Final state: baryonic, V0 particle...
- Work on amplitude analyses already ongoing.
  - Allows to measure many more Q2B branching fractions.
  - Allows to access more physics observables.



"Phase transition" in charmless analyses at LHCb from first observations to fully fledged amplitude analyses already started.

THANK YOU!

Backup: amplitude model

- EFKLLM has no cutoff compared to LASS

LASS

$$\mathcal{R}(m_{K\pi}) = \frac{m_{K\pi}}{p(m_{K\pi})\cot\delta_B - ip(m_{K\pi})} + e^{2i\delta_B}\frac{m_0^2\Gamma_0/p(m_0)}{(m_0^2 - m_{K\pi}^2 - im_0\frac{p(m)}{m_{K\pi}}\frac{m_0}{p(m_0)})},$$

where $\cot\delta_B = \frac{1}{ap(m) + \frac{1}{2}rp(m)}$.

EFKLLM

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

- Reduced K-matrix has been considered but not retained due to weak experimental constraints. F0(500) has been kept in the model

$$\mathcal{R}(m) = \frac{K(m)}{1 - i\rho(m)K(m)}\sqrt{\frac{p(m)}{m}\frac{p(m)}{M}},$$

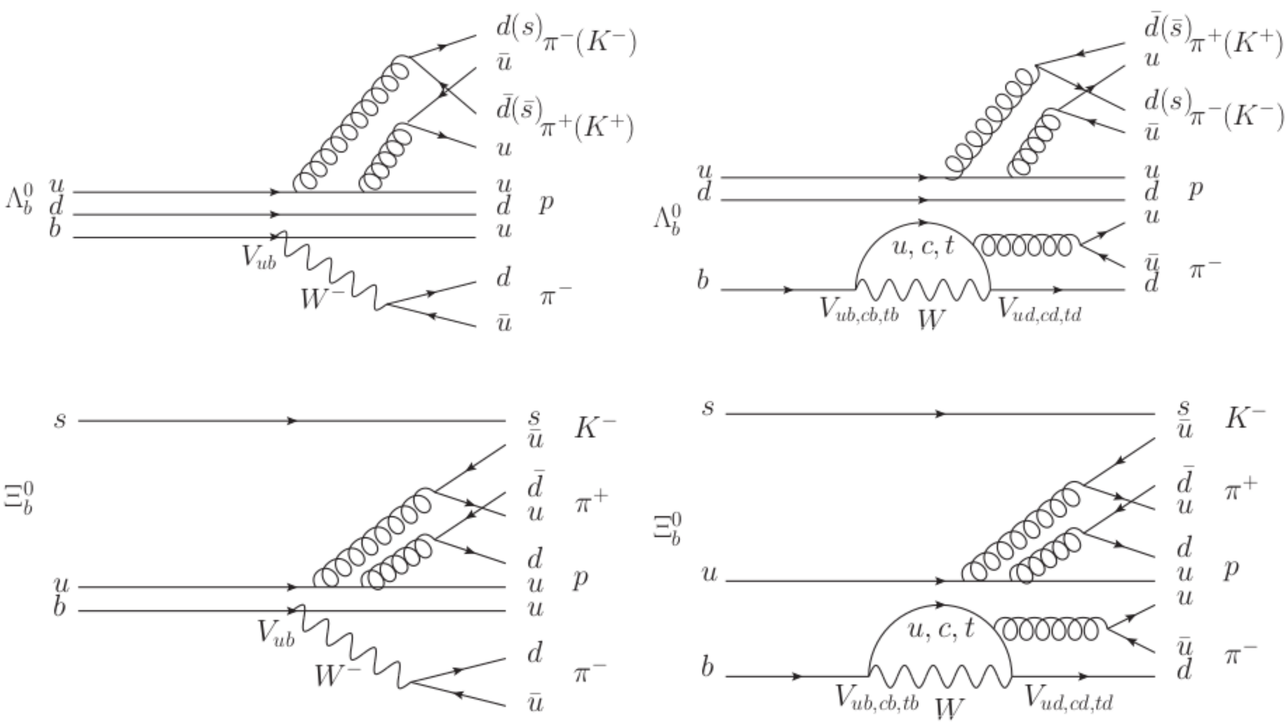
with

$$K(m) = K_{\text{res}}(m) + K_{\text{non-res}} = \frac{m_0\Gamma(m)}{(m_0^2 - m^2)\rho(m)} + \kappa,$$

Backup: Xb2p3h

Contribution	$\Lambda_b^0 \to pK^-\pi^+\pi^-$ (%)	$\Lambda_b^0 \to pK^-K^+K^-$ (%)	$\Xi_b^0 \to pK^-K^-\pi^+$ (%)
Experimental bias	±0.31 (±0.60)	±0.31 (±0.60)	±0.31
$C_{\widehat{T}}$ resolution	±0.01	±0.05	±0.02
Fit model	±0.03	±0.08	±0.19
Total	±0.31 (±0.60)	±0.32 (±0.61)	±0.36

- Experimental bias on CP is taken from Lb2Lcpi, where 0 ACP is expected.
  - P has to have the same than CP.
- Stat fully uncorrelated between bins, syst fully correlated.



(a) Tree diagram $\propto V_{ub} \sim \lambda^3$

(b) Penguin diagram $\propto \sum_{x=u,c,t} V_{bx}V_{xd} \sim \lambda^3$