CP violation in charmless beauty hadron decays at LHCb

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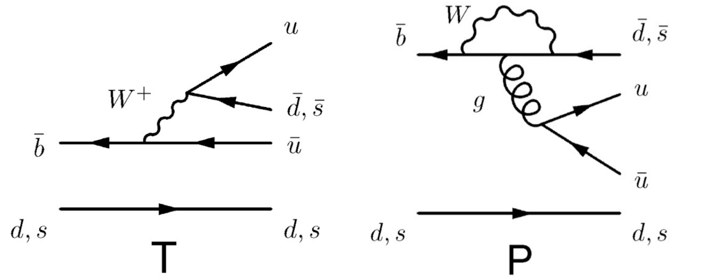
HQL 2021, CP violation session – 14th September 2021

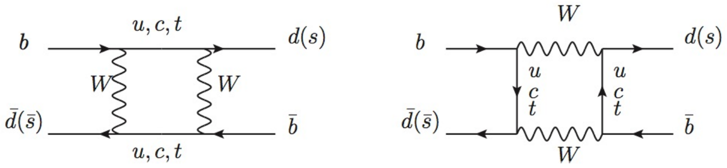
Outline

- Physics motivations
- The LHCb detector
- List of recent LHCb measurements
  - Search for CPV in $\Xi_b^- \to pK^-K^-$ [arXiv:2104.15074]
  - CPV with $B^+ \to K^+\pi^0$ [Phys. Rev. Lett. 126 (2021) 091802]
  - CPV in $B^0_{(s)} \to h^+h'^-$ (h = K, π) [JHEP 03 (2021) 075]
- Conclusions and outlook

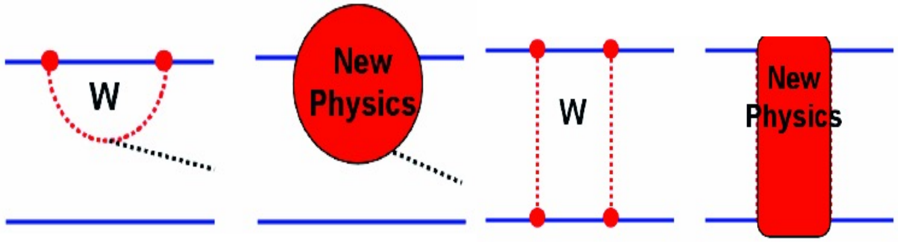
CP-violation in charmless B-hadron decays

- Charmless B-hadron decays are governed by **b→u** tree-level transitions and b→s(d) penguin transitions with comparable magnitudes thanks to CKM suppression
  - **Physics BSM in the loops** may be revealed by comparing measured quantities with SM predictions





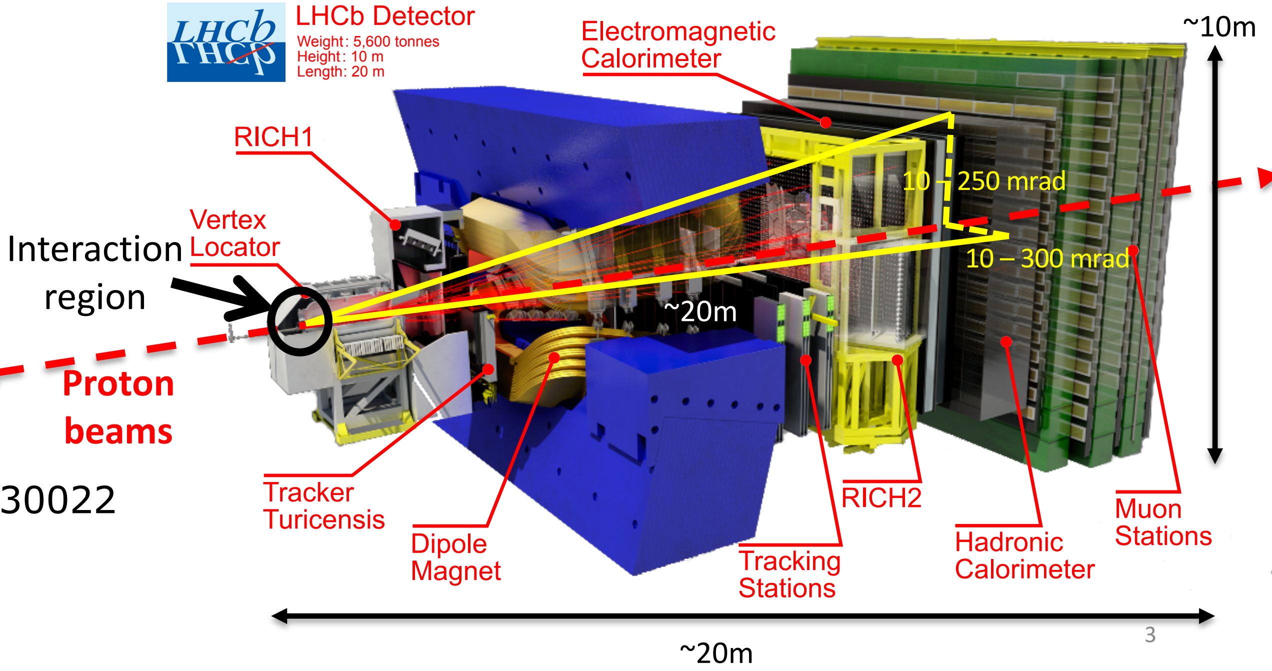
- Relevant quantities are **time-integrated** and **time-dependent CP asymmetries** and **branching fractions**
  - Observables are sensitive to **UT angles** and **$B^0_{(s)}$ mixing phases**
  - Interpretation in terms of CKM parameters is not trivial and requires combination of several measurements



The LHCb detector

- LHCb is a forward spectrometer
  - High geometrical efficiency in collecting $b\bar{b}$ and $c\bar{c}$ quark pairs
  - Excellent time resolution (σ_t ~ 45 fs), momentum resolution ($\delta p/p$ ~ 0.4-0.6%), PID performances (RICH)

JINST 3 S08005
Int. J. Mod. Phys. A 30 (2015)1530022



Search for CP violation in $\Xi_b^- \to pK^-K^-$ decays

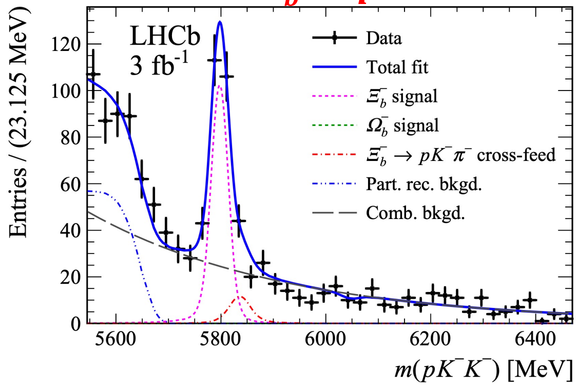
(LHCb-PAPER-2020-017 – arXiv:2104.15074)

Search for CP violation in $\Xi_b^- \to pK^-K^-$ decays

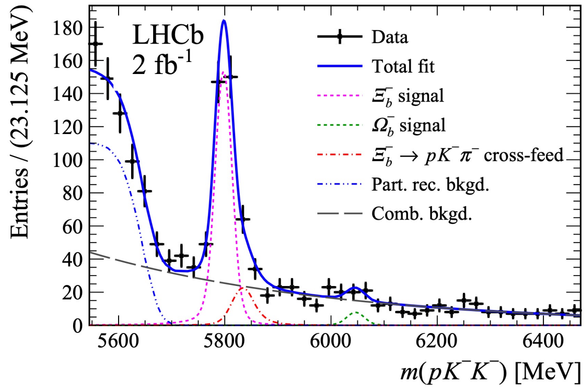
- $\Xi_b^- \to pK^-K^-$ first observed by LHCb with Run1 data (3 fb^{-1}) [PRL118(2017)071801]
- $\Xi_b^- \to pK^-K^-$ decay receives contributions from diagrams like those of $B^\pm \to 3h$ decays
  - **Potential to observe large CPV effects**
- Amplitude analysis of $\Xi_b^- \to pK^-K^-$ decay:
  - **First amplitude analysis of any baryon decay accounting for CPV**
  - Combine **Run1 (3 fb^{-1} @ 7/8 TeV) and part of Run2 (2 fb^{-1} @ 13 TeV)** data
  - **Search for $\Omega_b^- \to pK^-K^-$** decay and update limit on

$$\mathcal{R} = \frac{f_{\Omega_b^-}}{f_{\Xi_b^-}} \times \frac{\mathcal{B}(\Omega_b^- \to pK^-K^-)}{\mathcal{B}(\Xi_b^- \to pK^-K^-)}$$

Run1: 193 ± 21 $\Xi_b^- \to pK^-K^-$



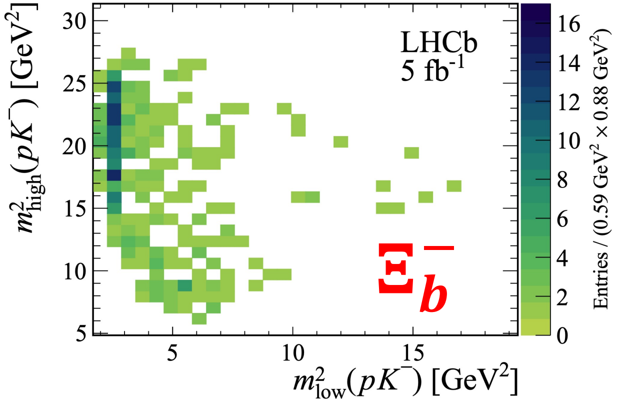
Run2: 297 ± 23 $\Xi_b^- \to pK^-K^-$

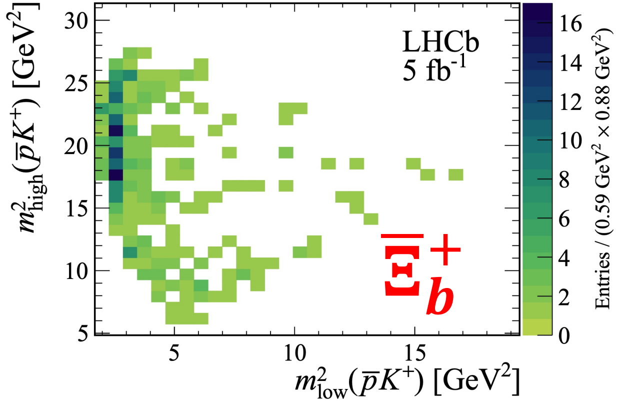


LHCb-PAPER-2020-017 – arXiv:2104.15074

Amplitude analysis of $\Xi_b^- \to pK^-K^-$

- Model-dependent analysis
  - Assuming **Ξ_b^- produced unpolarised**: only 2 variables to describe the decay dynamic
  - **Several Λ^* and Σ^* resonances are considered**
    - Start with $\Lambda(1520)$ only and add resonances maximising $\Delta(-2\ln L)$ until convergence is reached
  - Signal efficiency from simulation and calibration data
    - Separate for the two CC final states
- Signal region: m(Ξ_b^-) ± 40 MeV
  - Signal purity: **63%(Run1)** and **70%(Run2)**
  - Yields fixed from mass fits
- Backgrounds:
  - Combinatorial modelled from sideband
    - extrapolation to the signal region based NNet [JINST 16(2021)P06016]
  - Small $\Xi_b^- \to pK^-\pi^-$ contribution modelled from simulation





LHCb-PAPER-2020-017 – arXiv:2104.15074

Amplitude analysis results

CP asymmetries

Component	A^{CP} (10^{-2})
$\Sigma(1385)$	-27 ± 34 (stat) ± 73 (syst)
$\Lambda(1405)$	-1 ± 24 (stat) ± 32 (syst)
$\Lambda(1520)$	-5 ± 9 (stat) ± 8 (syst)
$\Lambda(1670)$	3 ± 14 (stat) ± 10 (syst)
$\Sigma(1775)$	-47 ± 26 (stat) ± 14 (syst)
$\Sigma(1915)$	11 ± 26 (stat) ± 22 (syst)

No evidence of CPV

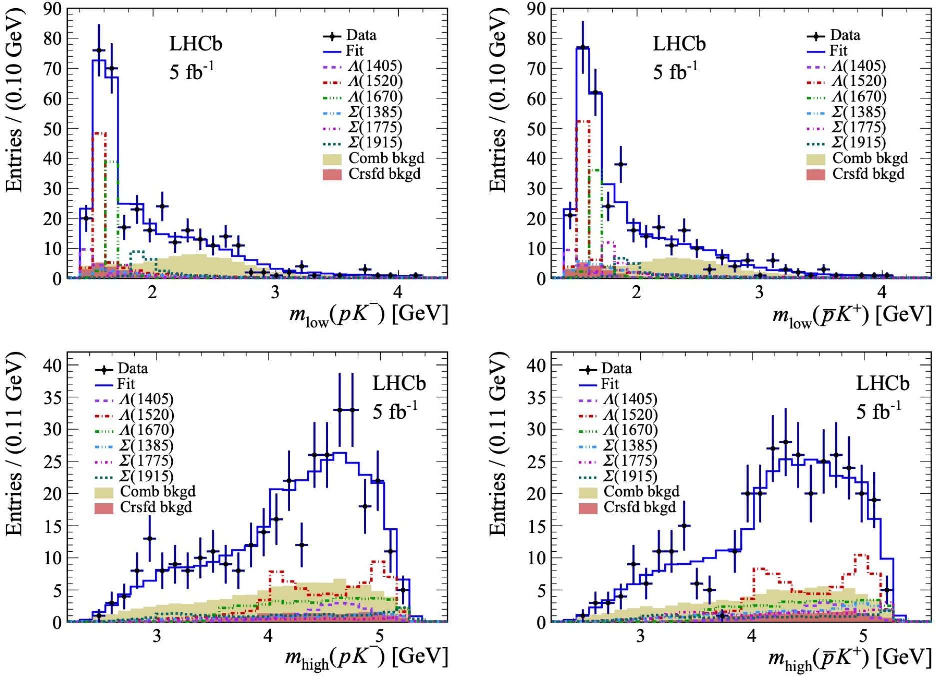
Branching fractions

$$\mathcal{B}\left(\Xi_b^- \to \Sigma(1385)K^-\right) = (0.26 \pm 0.11 \pm 0.17 \pm 0.10) \times 10^{-6}$$
$$\mathcal{B}\left(\Xi_b^- \to \Lambda(1405)K^-\right) = (0.19 \pm 0.06 \pm 0.07 \pm 0.07) \times 10^{-6}$$
$$\mathcal{B}\left(\Xi_b^- \to \Lambda(1520)K^-\right) = (0.76 \pm 0.09 \pm 0.08 \pm 0.30) \times 10^{-6}$$
$$\mathcal{B}\left(\Xi_b^- \to \Lambda(1670)K^-\right) = (0.45 \pm 0.07 \pm 0.13 \pm 0.18) \times 10^{-6}$$
$$\mathcal{B}\left(\Xi_b^- \to \Sigma(1775)K^-\right) = (0.22 \pm 0.08 \pm 0.09 \pm 0.09) \times 10^{-6}$$
$$\mathcal{B}\left(\Xi_b^- \to \Sigma(1915)K^-\right) = (0.26 \pm 0.09 \pm 0.21 \pm 0.10) \times 10^{-6}$$

$$\mathcal{B}\left(\Xi_b^- \to pK^-K^-\right) = (2.3 \pm 0.9) \times 10^{-6}$$

PRL118(2017)071801

LHCb-PAPER-2020-017 – arXiv:2104.15074



Simultaneous fit to Run1+Run2 data

Search for $\Omega_b^- \to pK^-K^-$

- Separate mass fits for Run1 and Run2 data are performed
  - Take into account different efficiencies and calibrations between the two samples
  - The two likelihood functions are combined in a unique result

$$\mathcal{R} \equiv \frac{f_{\Omega_b^-}}{f_{\Xi_b^-}} \times \frac{\mathcal{B}(\Omega_b^- \to pK^-K^-)}{\mathcal{B}(\Xi_b^- \to pK^-K^-)} = (24 \pm 21\,(\text{stat}) \pm 14\,(\text{syst})) \times 10^{-3}$$

LHCb-PAPER-2020-017 – arXiv:2104.15074

  - No evidence of $\Omega_b^- \to pK^-K^-$ decay is observed
  - Updated limits at 90% (95%) confidence level

$$\mathcal{R} \equiv \frac{f_{\Omega_b^-}}{f_{\Xi_b^-}} \times \frac{\mathcal{B}(\Omega_b^- \to pK^-K^-)}{\mathcal{B}(\Xi_b^- \to pK^-K^-)} < 62\ (71) \times 10^{-3}$$

LHCb-PAPER-2020-017 – arXiv:2104.15074

Systematic uncertainties

Uncorrelated sources	Run 1	Run 2
Ξ_b^- p_T distribution	<0.1	0.7
Hardware trigger efficiency	0.1	1.6
PID efficiency	0.1	0.6
Fixed parameters	0.8	0.5
Fit bias	0.5	<0.1
Total	1.0	1.9

Correlated sources	Run 1	Run 2	Combined
Phase-space distribution	8.9	22.5	10.6
Fit model choice	9.1	13.1	8.6
Total	–	–	13.6

Measurement of CP violation in $B^+ \to K^+\pi^0$ decays

[Phys. Rev. Lett. 126 (2021) 091802]

Measurement of CP violation in $B^+ \to K^+\pi^0$ decays

- Long-standing $B \to K\pi$ puzzle
  - Isospin relation implies $A_{CP}(B^+ \to K^+\pi^0) - A_{CP}(B^0 \to K^+\pi^-) = 0$ but current HFLAV WA is nonzero at almost 6σ

HFLAV2019

$$A_{CP}(B^+ \to K^+\pi^0) = 0.040 \pm 0.021$$
$$A_{CP}(B^0 \to K^+\pi^-) = -0.084 \pm 0.004$$

➡ $\Delta A_{CP}(K\pi) = 0.124 \pm 0.021$

  - Important to understand if effect is due to strong phases and amplitudes or to Physics BSM in the loops
  - Complete Kπ-puzzle sum rule

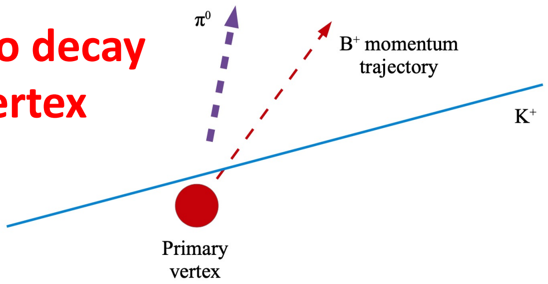
$$A_{CP}(K^+\pi^-)+A_{CP}(K^0\pi^+)\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+} = A_{CP}(K^+\pi^0)\frac{2\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_0}{\tau_+}+A_{CP}(K^0\pi^0)\frac{2\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

PLB627(2005)82

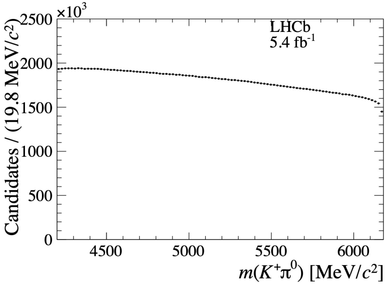
Measurement of CP violation in $B^+ \to K^+\pi^0$ decays

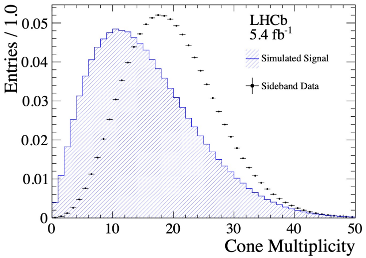
- Measurement based on full Run2 data ➔ 5.4 fb^{-1} @ 13 TeV
- Experimentally a very challenging decay at hadronic colliders
  - Candidates selected using a multivariate algorithm using isolation variables

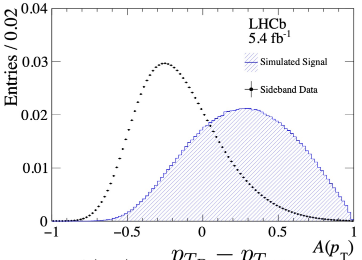
No decay vertex



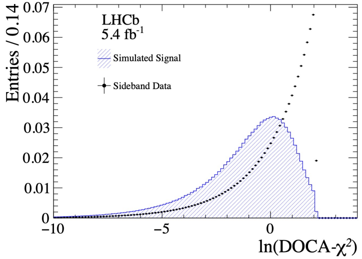
LHCB-PAPER-2020-040 SUPPLEMENTARY MATERIAL







$$\mathcal{A}(p_{\mathrm{T}}) = \frac{p_{T_B} - p_{T_{\mathrm{cone}}}}{p_{T_B} + p_{T_{\mathrm{cone}}}}$$



- Yields of charge-conjugate decays are determined from mass fits and raw asymmetry is corrected
  - Nuisance asymmetries determined using $B^+ \to J/\psi(\mu^+\mu^-)K^+$ decays

$$A_{CP}(B^+ \to K^+\pi^0) = A_{\mathrm{raw}}(B^+ \to K^+\pi^0) - A^B_{\mathrm{prod.}} - A^K_{\mathrm{det.}}$$

Measurement of CP violation in $B^+ \to K^+\pi^0$ decays

Phys. Rev. Lett. 126 (2021) 091802

- Result is better than previous WA

$$A_{CP}^{LHCb} = 0.025 \pm 0.015 \pm 0.006 \pm 0.003$$

stat. syst. input

$$A_{CP}^{WA} = 0.031 \pm 0.013$$

$$\Delta A_{CP}^{WA}(K\pi) = 0.115 \pm 0.014$$

Nonzero at 8σ

- From Kπ–puzzle sum rule

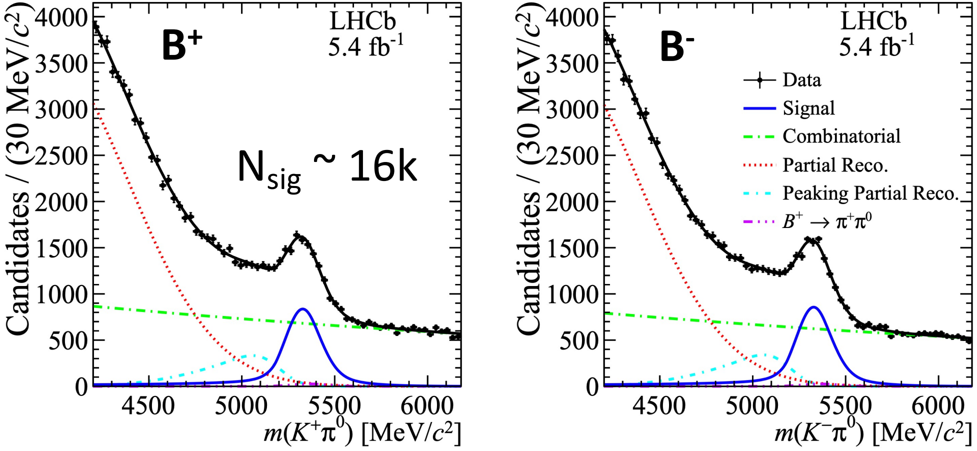
$$A_{CP}^{SR}(B^0 \to K^0\pi^0) = -0.138 \pm 0.025$$

in agreement with current WA but still large error in experimental determination

$$A_{CP}^{WA}(B^0 \to K^0\pi^0) = 0.01 \pm 0.10$$

- More insight is needed to uncover Physics BSM

[JHEP01(2018)074,PLB785(2018)525]



Systematic	Value ($\times 10^{-3}$)
Signal modeling shape	4.3
Combinatorial background shape	1.3
Partial reco. background shape	1.3
Peaking partial reco. background shape	1.2
Peaking partial reco. background offset	1.3
Peaking partial reco. background resolution	1.4
$B^+ \to \pi^+\pi^0$ yield	1.3
$B^+ \to \pi^+\pi^0$ CP asymmetry	1.5
Multiple candidates	1.3
Production/detection asymmetry stat.	2.1
Production/detection asymmetry weights	0.5
Sum in quadrature	6.1

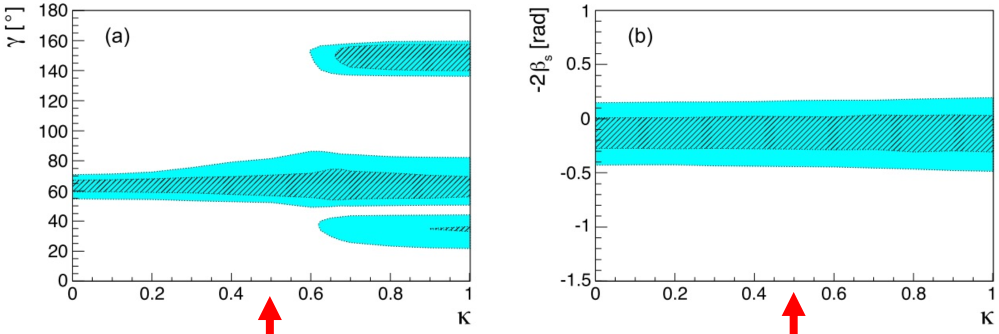
CP violation in charmless two-body $B^0_{(s)}$ decays

[JHEP 03 (2021) 075]

CP-violation in $B^0_{(s)} \to h^+h'^-$ decays

- CPV observables are sensitive to CKM angles γ and α, and $B^0_{(s)}$ mixing phases ϕ_s and ϕ_d
  – presence of loop diagrams gives **sensitivity to physics beyond SM**
  – Combination of several quantities from different decays to **keep under control hadronic uncertainties**

Phys. Lett. B741 (2015) 1



$\gamma = (63.5^{+7.2}_{-6.7})^\circ$,

$-2\beta_s = -0.12^{+0.14}_{-0.16}$ rad.

Up to 50% non factorisable U-spin breaking effects

Compatible with tree-level determinations

Combination of several $B^0_{(s)} \to h^+h'^-$ observables

[PLB459(1999)306, PJC71(2011)1532, JHEP10(2012)029, PRD94(2016)113014]

CP-violation in $B^0_{(s)} \to h^+ h'^-$ decays

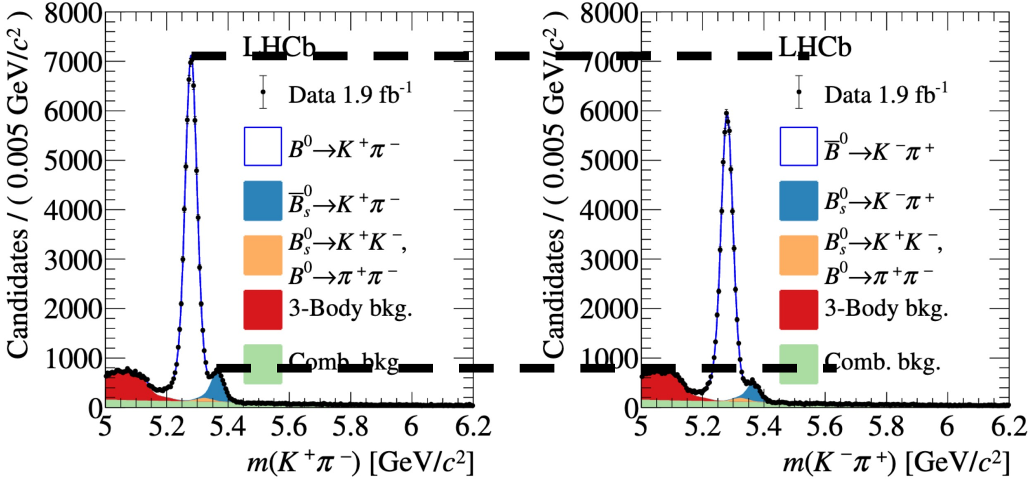
- Analysis based on 2015 + 2016 data → ~ 1.9 fb^{-1} @ 13 TeV
  - Time-dependent CPV in $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$
  - Time-integrated CPV in $B^0 \to K^+\pi^-$ and $B^0_s \to K^-\pi^+$
- Two strategies are used to cross-check each other

	"Simultaneous*"	"Per-event"
Fit	Simultaneous fit to $\pi^+\pi^-$, K^+K^-, $K^+\pi^-$ and π^+K^- samples	Independent fit to background-subtracted $\pi^+\pi^-$ and K^+K^- samples
Decay Time Resolution	Averaged resolution for all events	Per-event resolution as a function of decay time error
Flavour tagging	Distinct OS and SS taggers, **calibrated during the fit with $B^0 \to K^+\pi^-$ decays**	Single combined tagger, calibrated before the fit
Acceptance correction	Calibrated using $B^0 \to K^+\pi^-$	Per-event swimming method **(see backup slides)**

*: results from this method are used for the combination with Run1

CP-violation in $B^0_{(s)} \to h^+ h'^-$ decays

LHCb-PAPER-2020-029 SUPPLEMENTARY MATERIAL



Combination with Run1 results

$$A_{CP}^{B^0} = -0.0831 \pm 0.0034$$

$$A_{CP}^{B_s^0} = 0.225 \pm 0.012$$

JHEP 03 (2021) 075

Run1 results: PRD98(2018)032004

- **CP asymmetries of $B^0 \to K^+\pi^-$ and $B_s^0 \to K^-\pi^+$** are determined
- The time-dependent fit allows to remove effect from production asymmetry
- Detection asymmetry is studied from prompt $D^+ \to K^+\pi^+\pi^-$ and $D^+ \to K_S^0\pi^+$ decays

Test for the SM [PLB621(2005)126]

$$\Delta = \frac{A_{CP}^{B^0}}{A_{CP}^{B_s^0}} + \frac{B(B_s^0 \to K^-\pi^+)}{B(B^0 \to K^+\pi^-)}\frac{\Gamma_s}{\Gamma_d} = -0.085 \pm 0.025 \pm 0.035$$

Should be 0 in SM → No evidence of BSM effects

CP asymmetries of $B^0 \to \pi^+\pi^-$ decays

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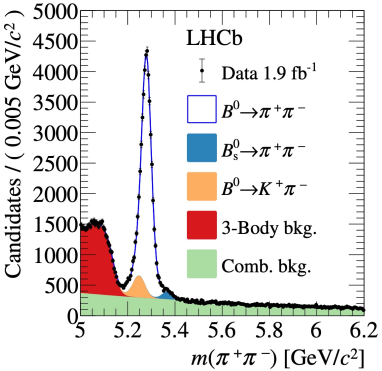
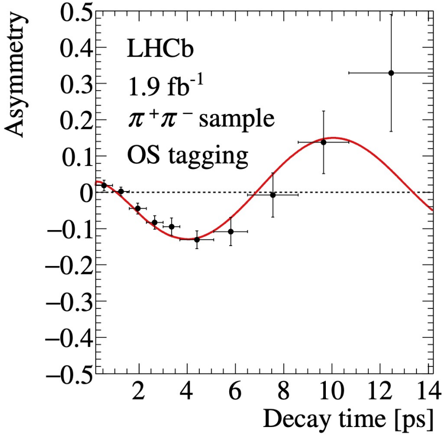
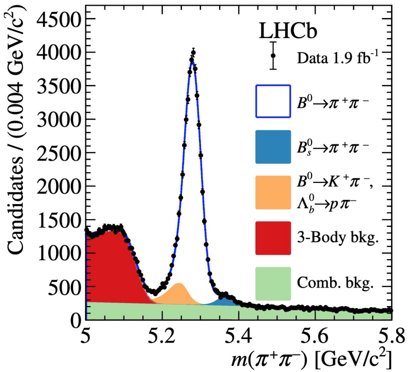
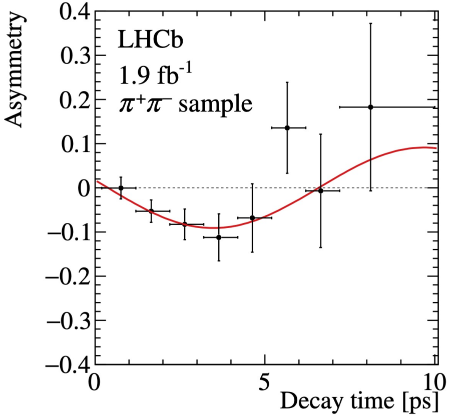
Simultaneous method





Per-event method





Combination with Run1 results

Full covariance matrices are taken into account

$$C_{\pi\pi} = -0.320 \pm 0.038$$
$$S_{\pi\pi} = -0.672 \pm 0.034$$

JHEP 03 (2021) 075

Run1 results: PRD98(2018)032004

Most precise determination of these quantities to date

In agreement with BaBar and Belle results

[PRD87(2013)052009, PRD88(2013)092003]

$$A_{CP}(t) = \frac{-C_f\cos(\Delta m t) + S_f \sin(\Delta m t)}{\cosh\frac{\Delta\Gamma}{2}t + A_f^{\Delta\Gamma}\sinh\frac{\Delta\Gamma}{2}t}$$

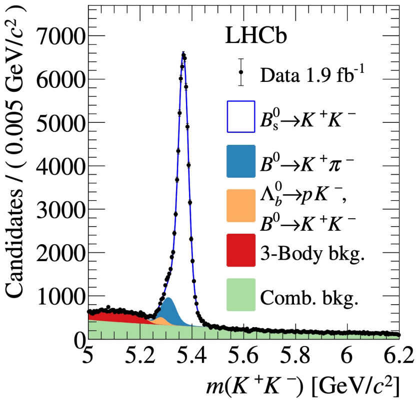
C_f = CPV in decay

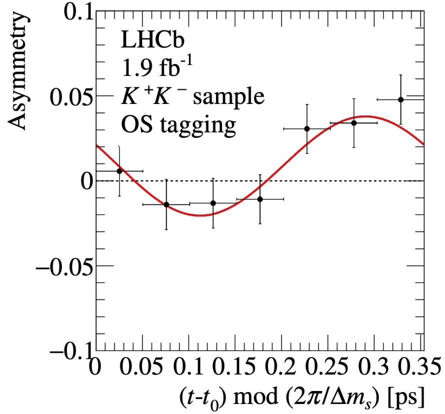
S_f = mixing-induced CPV

CP-violation in $B_s^0 \to K^+K^-$ decays

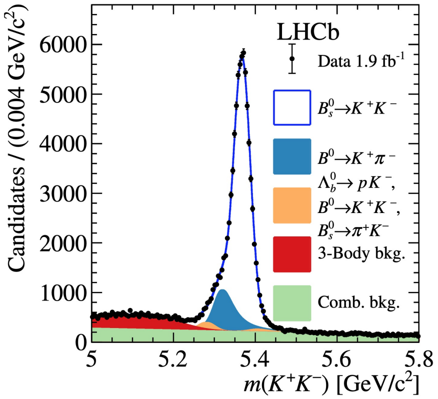
JHEP 03 (2021) 075

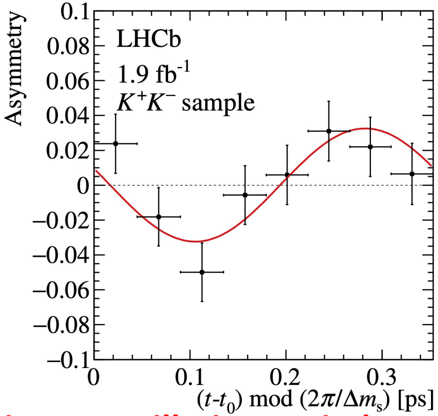
Simultaneous method





Per-event method





Decay time is folded into 1 oscillation period

Combination with Run1 results

Full covariance matrices are taken into account

$$C_{KK} = 0.172 \pm 0.031$$
$$S_{KK} = 0.139 \pm 0.032$$
$$\mathcal{A}_{KK}^{\Delta\Gamma} = -0.897 \pm 0.087$$

JHEP 03 (2021) 075

Run1 results: PRD98(2018)032004

$(C_{KK}, S_{KK}, A_{KK}^{\Delta\Gamma}) \neq (0, 0, -1)$ @ 6.5σ

$(C_{KK}, S_{KK}) \neq (0, 0)$ @ 6.7σ

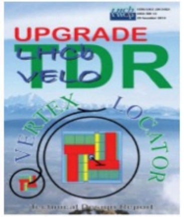
First observation of time-dependent CPV in B_s^0 decays!!!

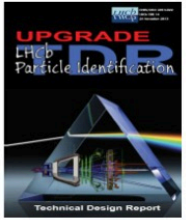
Unitary relation check

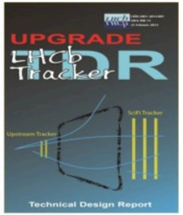
$$\sqrt{C_{KK}^2 + S_{KK}^2 + A_{KK}^2} = 0.93 \pm 0.08$$

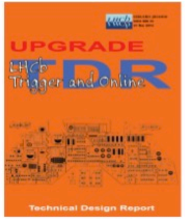
A look to the near future

- LHCb Upgrade will restart together with LHC soon
  - Plan to collect **x5 more data** in the same time working with **x5 more complicated events**
  - Almost completely redesigned detector and trigger
  - See Federico Alessio's talk on Thursday for more details



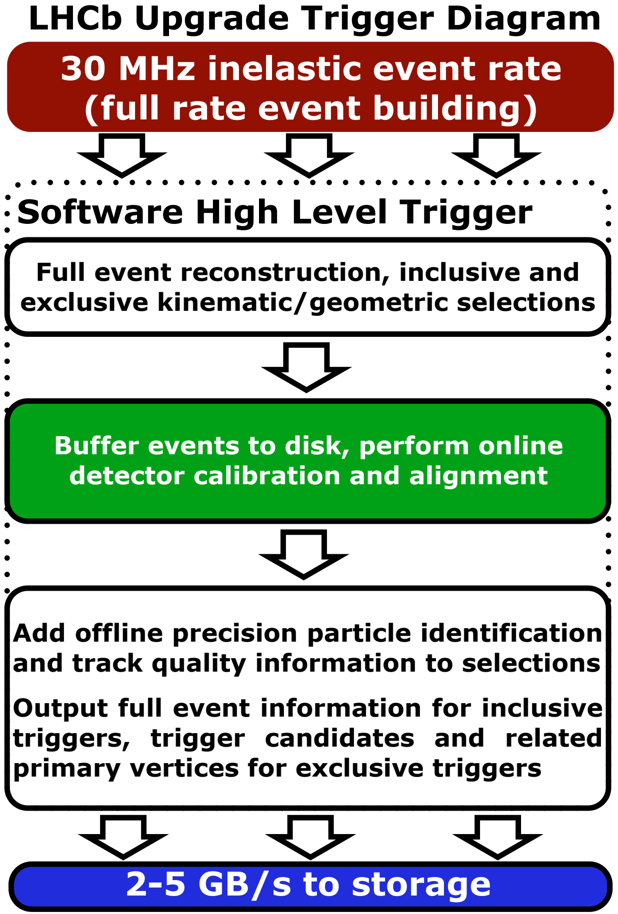






If it pleases Covid-19

LHC era			HL-LHC era
Run 1 (2010-12)	Run 2 (2015-18)	Run 3 (2022-24)	Run 4 (2027-30)
3 fb^{-1}	9 fb^{-1}	23 fb^{-1}	46 fb^{-1}



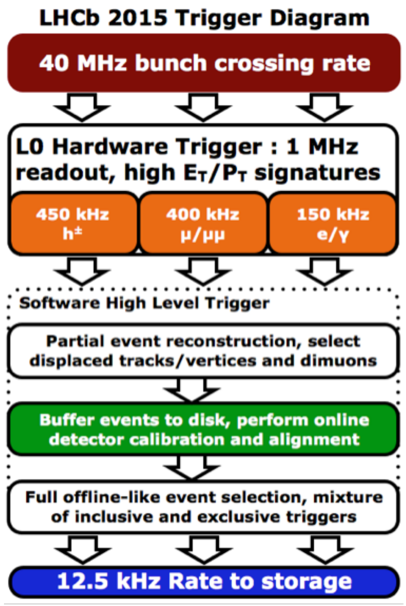
Conclusions and outlook

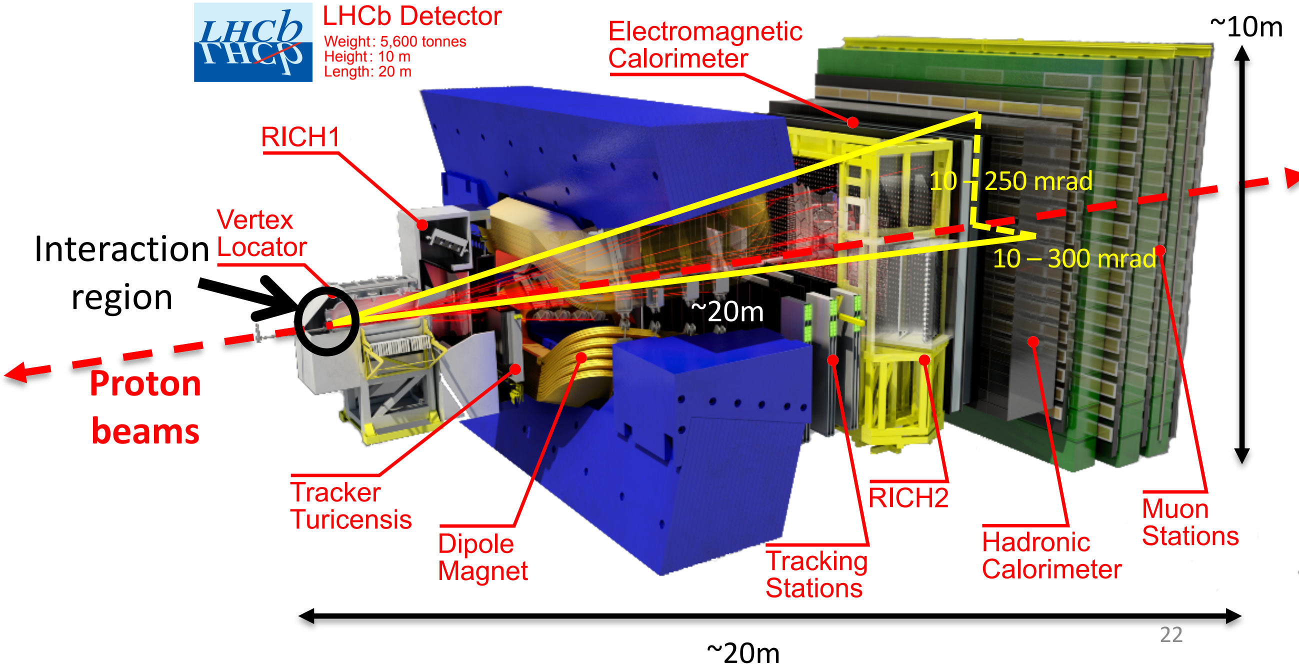
- Most recent CP-violation measurement in charmless B decays at LHCb have been presented
- Amplitude analysis of $\Xi_b^- \to pK^-K^-$ decay [LHCb-PAPER-2020-017 – arXiv:2104.15074]
  – **First amplitude analysis of a baryon accounting for CPV**
  – No evidence for CPV but **still 2017+2018 data to exploit**
  – Will benefit from more statistics but need to check model-related systematics
- CP asymmetry in $B^+ \to K^+\pi^0$ decay [Phys. Rev. Lett. 126 (2021) 091802]
  – Very challenging analysis at hadronic machines
  – Measurement **more precise than previous WA**
  – Prospects are strongly dependent on **performances with higher occupancies** expected in Run3 and beyond (especially **ECAL performances**)
- CP violation in $B_s^0 \to h^+h'^-$ decays [JHEP 03 (2021) 075]
  – **First observation ever of time-dependent CP violation in the B_s^0 sector**
  – Will benefit a lot from **including 2017+2018** data and from **Run3 statistics**
  – Explore **time-dependent measurement of rarest modes like $B_s^0 \to \pi^+\pi^-$**

Backup

The LHCb detector

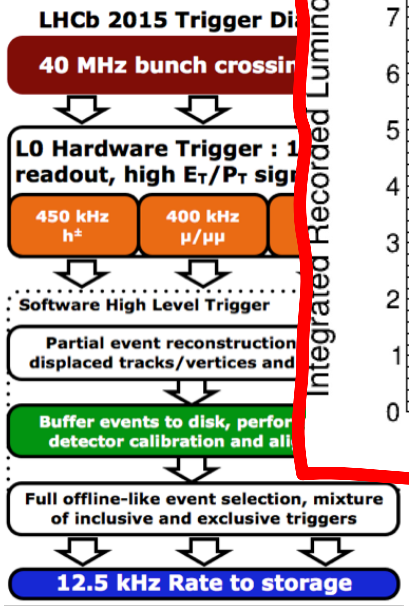
- LHCb is a forward spectrometer
  - Great time resolution (σ_t ~ 45 fs), momentum resolution ($\delta p/p$ ~ 0.4-0.6%), PID performances (RICH)
  - Real time calibration of detector

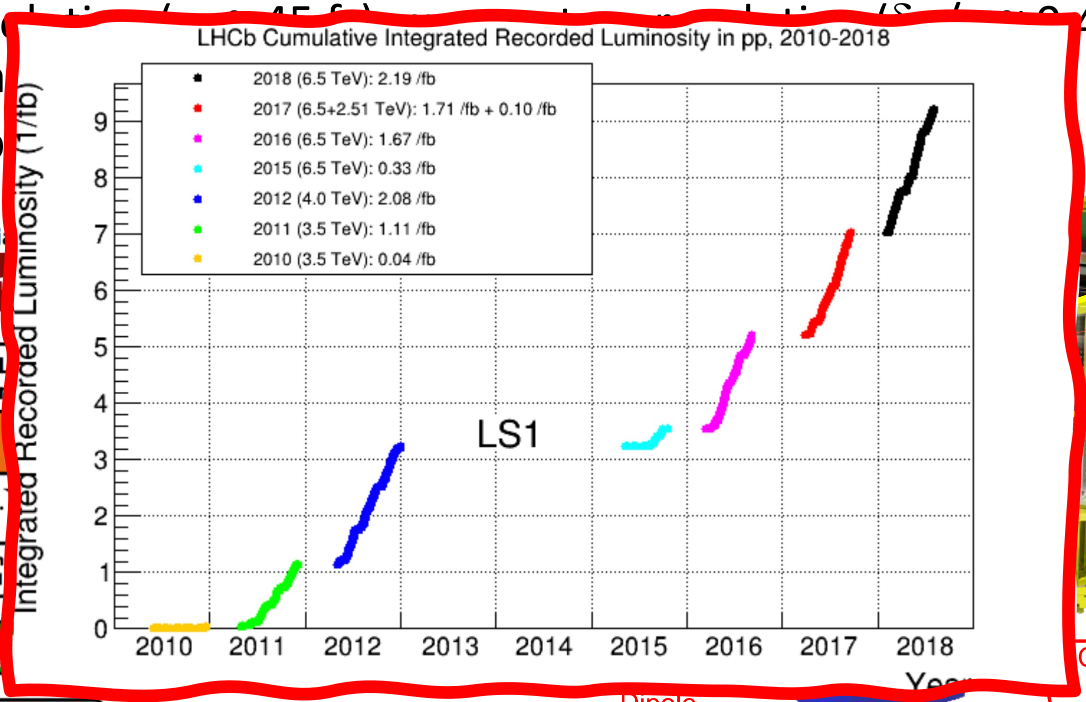


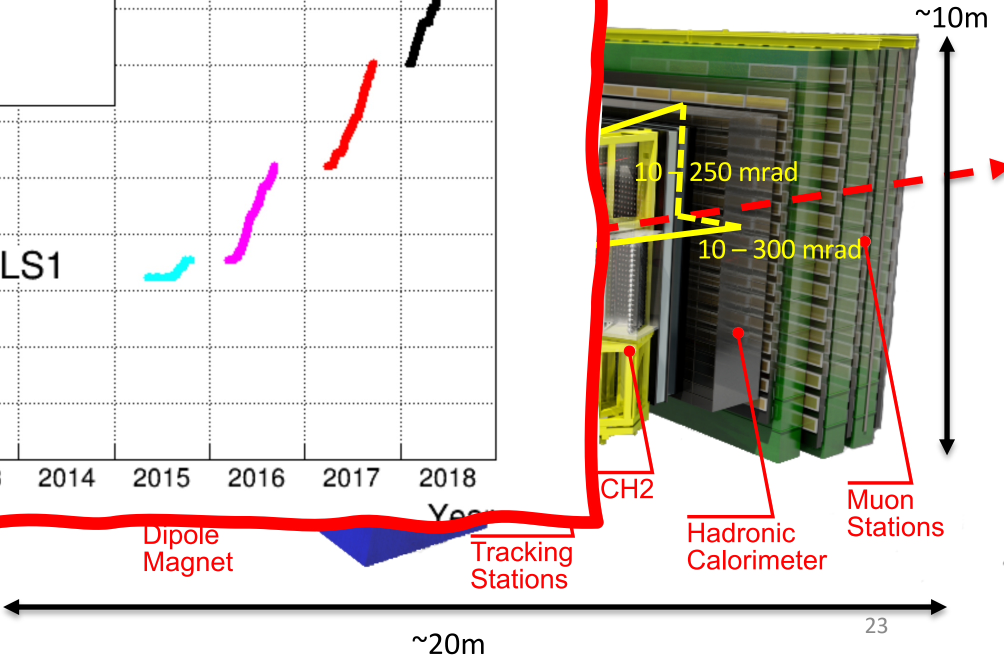


The LHCb detector

- LHCb is a forward spectrometer
  - Great time res … 4-0.6%),
    PID performan
  - Real time calib

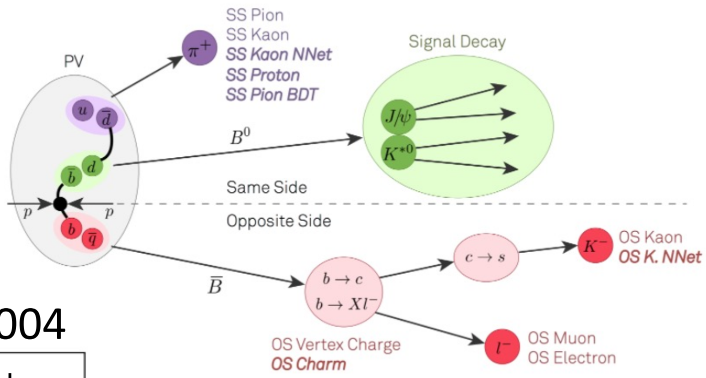






Key ingredients of TD measurements

- Determination of B flavour at production
  - Dilution factor $D_{tag} = 1 - 2\omega$ of the asymmetry
  - ω = mistag fraction
- Decay time resolution
  - Dilution factor $D_{res} = e^{-\frac{\sigma_t^2 \Delta m^2}{2}}$
  - σ_t = decay-time resolution
  - Very important for B_s^0
- Decay-time efficiency $\varepsilon(t)$
  - Introduced by reconstruction and selection requirements
  - Crucial for the determination of (effective) lifetimes



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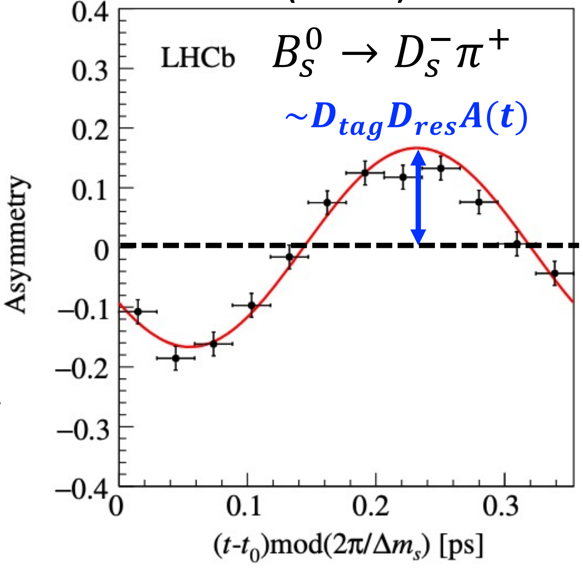

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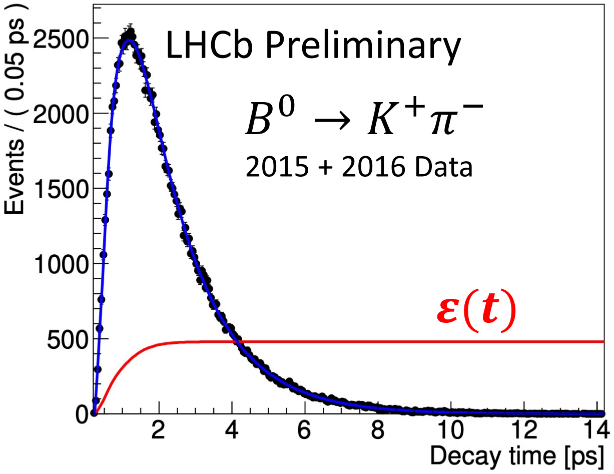
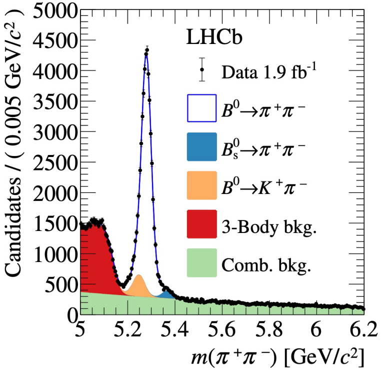
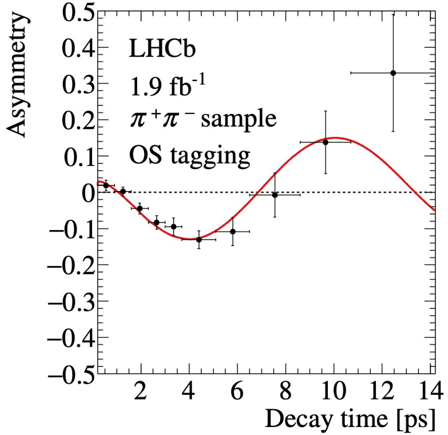


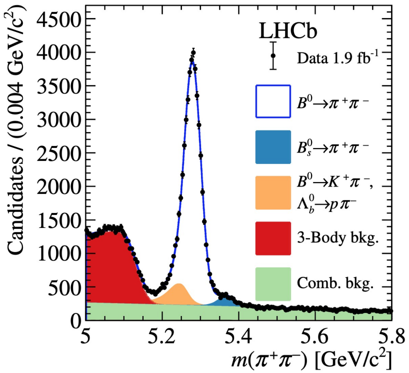
CP-violation in $B^0_{(s)} \to h^+ h'^-$ decays

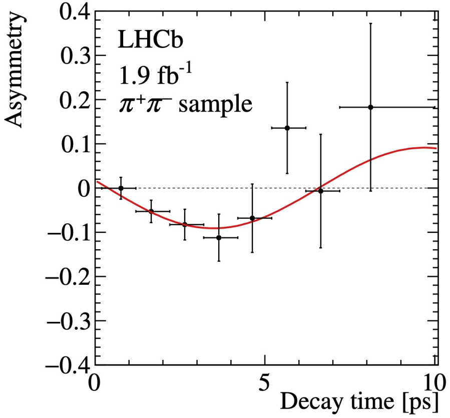
Simultaneous method





Per-event method





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Simultaneous method

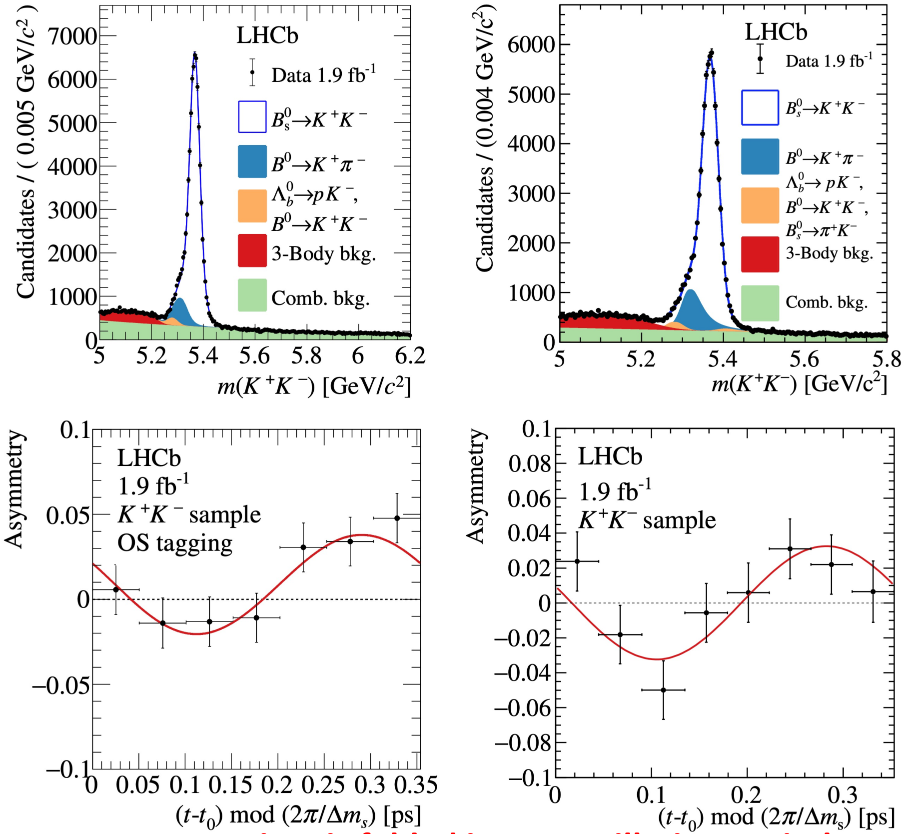
$$C_{\pi\pi} = -0.311 \pm 0.045,$$
$$S_{\pi\pi} = -0.706 \pm 0.042,$$

Per-event method

$$C_{\pi\pi} = -0.338 \pm 0.048,$$
$$S_{\pi\pi} = -0.673 \pm 0.043,$$

CP-violation in $B^0_{(s)} \rightarrow h^+h'^-$ decays

Simultaneous method — **Per-event method**



Decay time is folded into 1 oscillation period

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Simultaneous method

$$C_{KK} = 0.164 \pm 0.034,$$
$$S_{KK} = 0.123 \pm 0.034,$$
$$\mathcal{A}^{\Delta\Gamma}_{KK} = -0.833 \pm 0.054,$$

Per-event method

$$C_{KK} = 0.173 \pm 0.042,$$
$$S_{KK} = 0.166 \pm 0.042,$$
$$\mathcal{A}^{\Delta\Gamma}_{KK} = -0.973 \pm 0.071$$

CP-violation in $B^0_{(s)} \to h^+ h'^-$ decays

Simultaneous method | Per-event method

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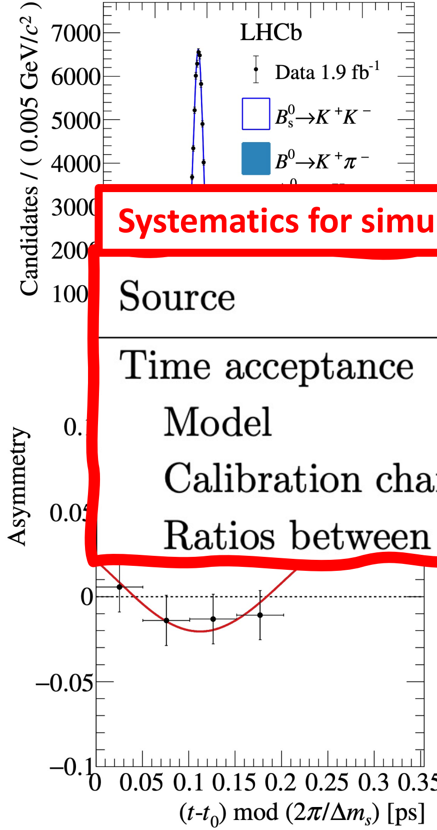

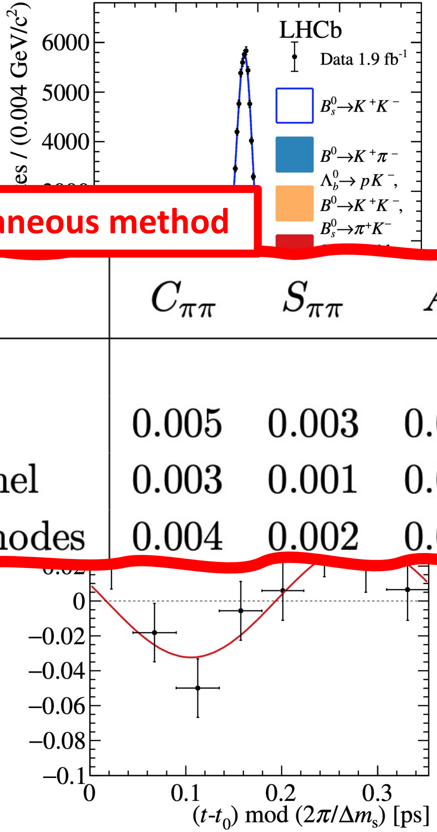

Simultaneous method

$$C_{KK} = 0.164 \pm 0.034,$$
$$S_{KK} = 0.123 \pm 0.034$$

Systematics for simultaneous method

Source	$C_{\pi\pi}$	$S_{\pi\pi}$	$A_{CP}^{B^0}$	$A_{CP}^{B_s^0}$	C_{KK}	S_{KK}	$\mathcal{A}_{KK}^{\Delta\Gamma}$
Time acceptance							
Model	0.005	0.003	0.0005	0.001	0.003	0.003	0.045
Calibration channel	0.003	0.001	0.0003	0.006	0.001	0.001	0.047
Ratios between modes	0.004	0.002	0.0010	0.000	0.001	0.001	0.047

Completely uncorrelated between methods

$$S_{KK} = 0.166 \pm 0.0$$
$$\mathcal{A}_{KK}^{\Delta\Gamma} = -0.973 \pm 0.0$$

CP-violation in $B^0_{(s)} \to h^+h'^-$ decays

- Compatibility between the two methods is determined with pseudoexperiments
  - Generate pseudodata with one fitting model and fit with both
  - Largest difference for $A^{KK}_{\Delta\Gamma}$ but large uncorrelated systematic uncertainties
  - Global compatibility is at 1.5σ dominated by difference in $A^{KK}_{\Delta\Gamma}$

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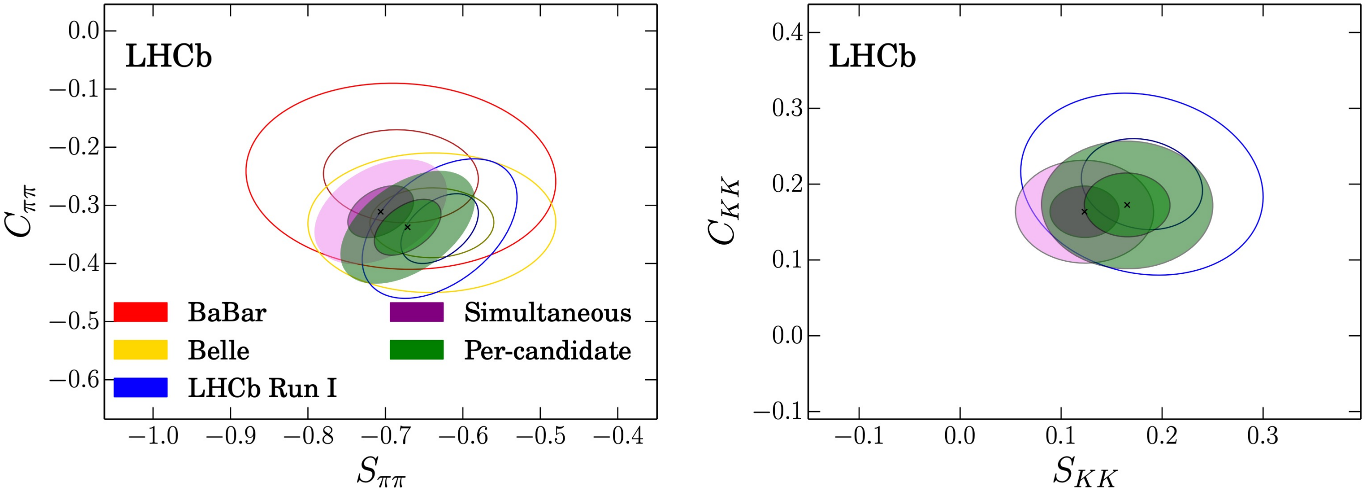

CP-violation in $B^0_{(s)} \to h^+h'^-$ decays

Systematic uncertainties for simultaneous method

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Source	$C_{\pi\pi}$	$S_{\pi\pi}$	$A_{CP}^{B^0}$	$A_{CP}^{B^0_s}$	C_{KK}	S_{KK}	$\mathcal{A}_{KK}^{\Delta\Gamma}$
Time acceptance							
Model	0.0048	0.0027	0.0005	0.0005	0.0028	0.0029	0.0450
Calibration channel	0.0028	0.0013	0.0003	0.0057	0.0009	0.0009	0.0470
Transport between modes	0.0038	0.0019	0.0010	0.0001	0.0010	0.0007	0.0470
Time resolution							
Width	0.0015	0.0026	0.0001	0.0001	0.0087	0.0095	0.0000
Bias	0.0003	0.0003	0.0000	0.0000	0.0035	0.0034	0.0000
Average	0.0004	0.0007	0.0000	0.0000	0.0038	0.0038	0.0043
Input parameters	0.0029	0.0018	0.0001	0.0001	0.0055	0.0070	0.0471
B^0_s from B^+_c	–	–	–	–	0.0040	0.0032	0.0036
Flavour tagging							
SSK calibration	–	–	–	–	0.0033	0.0042	0.0001
Calibration model	0.0012	0.0013	0.0000	0.0000	0.0037	0.0034	0.0012
$H_b \to h^+h'^-$ mass model	0.0065	0.0078	0.0004	0.0074	0.0017	0.0018	0.0057
Cross-feed model	0.0075	0.0044	0.0001	0.0001	0.0011	0.0001	0.0015
Comb. bkg. model	0.0057	0.0030	0.0001	0.0015	0.0005	0.0005	0.0064
Part. reco. model	0.0043	0.0063	0.0005	0.0036	0.0012	0.0013	0.0113
PID in fit model	0.0020	0.0031	0.0002	0.0016	0.0004	0.0006	0.0013
PID asymmetry	–	–	0.0028	0.0028	–	–	–
Det. asymmetry	–	–	0.0012	0.0012	–	–	–
Total	0.0145	0.0128	0.0033	0.0108	0.0137	0.0149	0.0944

Per-event decay-time efficiency (Swimming)

- Acceptance corrected on per-event basis
- B-hadrons are moved along their momentum vector and decay time biasing selections are re-evaluated ("swimming method")
- Each hypothetical decay time is assigned a 0 (not accepted) or 1 (accepted). Transition times are called turning points
  - Acceptance is a step function within the "start" and "end" turning points of the event
- Biasing selections are:
  - Mother and daughter IP χ^2
  - DIRA
  - Flight distance χ^2
  - BDT
- Additional requirements on:
  - Radial flight distance
  - VELO acceptance
  - HLT1TrackMVA (it's an OR of the selected tracks)