Measurements of CP violation in charmless 2-body B-meson decays at LHCb

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On behalf of the LHCb collaboration

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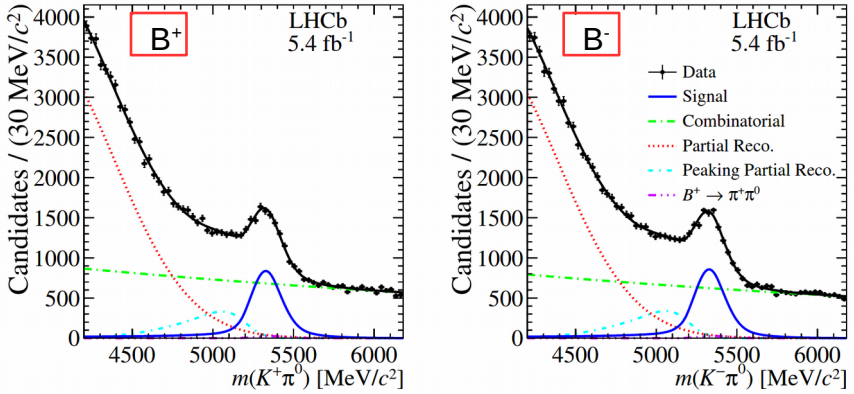
Measurements of CP violation in charmless 2-body B-meson decays at LHCb

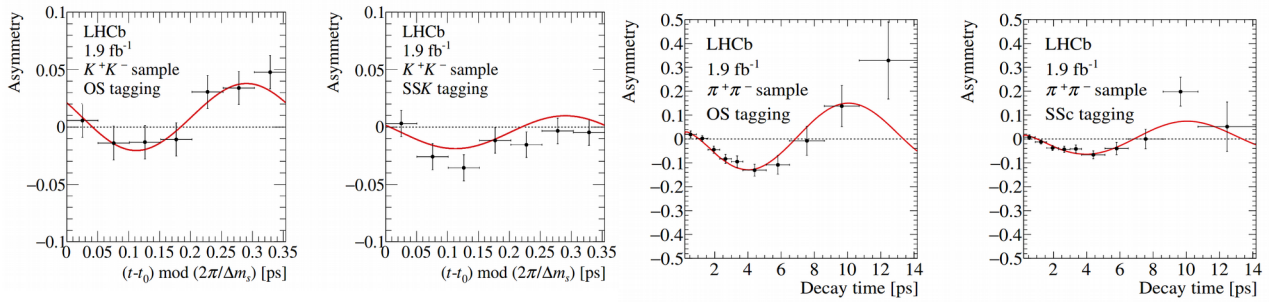
- Measurement of CP violation in the decay $B^+ \to K^+\pi^0$

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



- Observation of CP violation in 2-body $B^0_{(s)}$-meson decays to charged pions and kaons

[JHEP 03 (2021) 075]



Measurement of CP violation in the decay $B^+ \to K^+\pi^0$ - Introduction and motivations

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

$B \to K\pi$ decays dominated by hadronic loop amplitudes in the Standard Model

Contributions from tree-level and electroweak loop-level process → sensitivity to new physics

CP-asymmetries resulting from interference between tree- and loop-level amplitudes

$B \to K\pi$ amplitudes obey isospin relations

→ Inconsistent with the difference between $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ CP-asymmetries

Before this analysis → $A_{CP}(B^+ \to K^+\pi^0) = 0.040 \pm 0.021$; $A_{CP}(B^0 \to K^+\pi^-) = -0.084 \pm 0.004$ [HFLAV]

Difference is nonzero with 5.5σ

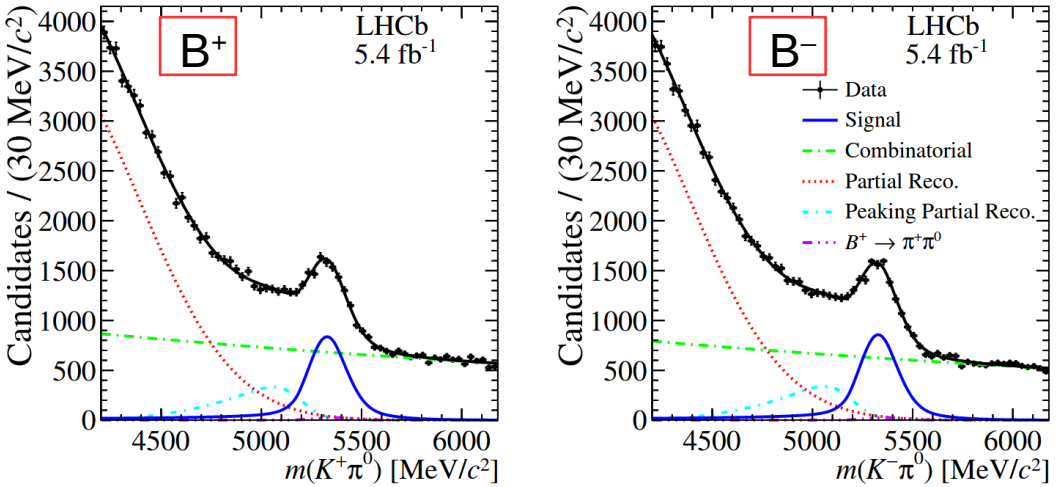
Key inputs to understand the Kπ-puzzle

Kπ-puzzle sum rule:

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

$B^+ \to K^+\pi^0$ – Data samples and observables

Data sample of 5.4 fb^{-1}, 2016-2018



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

Signal yield

16 683 ± 719 B^+

Direct CP-asymmetry in the $B^+ \to K^+\pi^0$ decay

$$A_{CP} = \frac{\Gamma(B^- \to K^-\pi^0) - \Gamma(B^+ \to K^+\pi^0)}{\Gamma(B^- \to K^-\pi^0) + \Gamma(B^+ \to K^+\pi^0)}$$

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

A^B_{prod} → production asymetry of $B^\pm$ mesons

A^K_{det} → asymmetry in detection, triggering and reconstruction of the $K^\pm$ mesons

$B^+ \to K^+\pi^0$ - Results

Nuisance asymmetries measured with $B^+ \to (J/\psi \to \mu^+ \mu^-) K^+$ decays control sample
→ purity ~ 99%

$$A^B_{\text{prod.}} + A^K_{\text{det.}} = A_{\text{raw}}(B^+ \to J/\psi K^+) - A_{CP}(B^+ \to J/\psi K^+)$$

$$A_{CP}(B^+ \to K^+\pi^0) = A_{\text{raw}}(B^+ \to K^+\pi^0) - A_{\text{raw}}(B^+ \to J/\psi K^+) + A_{CP}(B^+ \to J/\psi K^+)$$

From [PDG] $A_{CP}(B^+ \to J/\psi\, K^+) = 0.002 \pm 0.003$

$$A_{CP}(B^+ \to K^+\pi^0) = 0.025 \pm 0.015 \pm 0.006 \pm 0.003$$

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

Statistical | Systematic | External input

Consistent with the world average $A_{CP}(B^+ \to K^+\pi^0) = 0.040 \pm 0.021$ [HFLAV]
Consistent with zero within 1.5σ

$B^+ \to K^+\pi^0$ – Results

Measurement exceeds the precision of the current world average $A_{CP}(B^+ \to K^+\pi^0) = 0.040 \pm 0.021$ [HFLAV]

New world average $\to A_{CP}(B^+ \to K^+\pi^0) = 0.031 \pm 0.013$

CP-asymmetry difference $\Delta A_{CP}(K\pi) \equiv A_{CP}(B^+ \to K^+\pi^0) - A_{CP}(B^0 \to K^+\pi^-)$

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

Nonzero with a significance greater the 8σ

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

Sum rule prediction of $A_{CP}(B^0 \to K^0\pi^0) = -0.138 \pm 0.025$

[JHEP 03 (2021) 075]

Contribution from tree and penguin process → sensitivity to new physics

Neutral B-mixing process → time-dependent CP-asymmetry

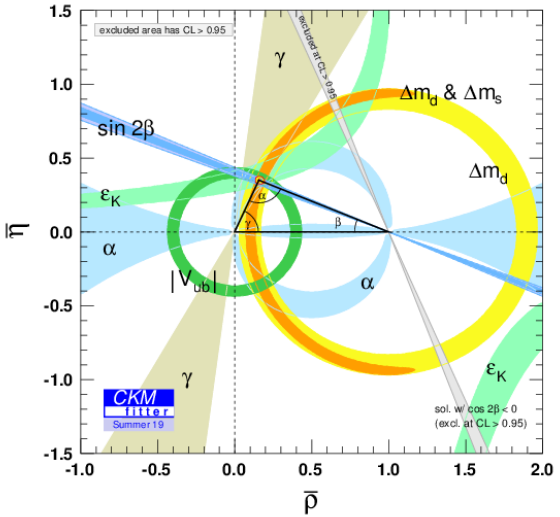
B-meson CP-asymmetries can help constrain CKM quantities → α, –2βs, γ

Data sample of 2 fb^{-1}, 2015-2016

Combined with Run1 analysis, data sample of 3 fb^{-1}, 2011-2012
[Phys. Rev.D98(2018) 032004]

Measured time-integrated CP violation in $B^0_{(s)} \to K\pi$ decays

Measured time-depedent CP-asymmetry in $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays



$B^0_{(s)} \to K\pi$, $B^0 \to K\pi$, $B^0 \to \pi^+\pi^-$, $B^0_s \to K^+K^-$ – Observables

Measured time-integrated CP violation in $B^0_{(s)} \to K\pi$ decays

$$A_{CP} = \frac{\left|\overline{A}_{\overline{f}}\right|^2 - \left|A_f\right|^2}{\left|\overline{A}_{\overline{f}}\right|^2 + \left|A_f\right|^2}$$

$\overline{A}_{\overline{f}}$ is the $\overline{B}^0_{(s)} \to \overline{f}$ decay amplitude

A_f is the $B^0_{(s)} \to f$ decay amplitude

f is the final state of the decay

Measured time-depedent CP-asymmetry in $B^0 \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$ decays

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

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

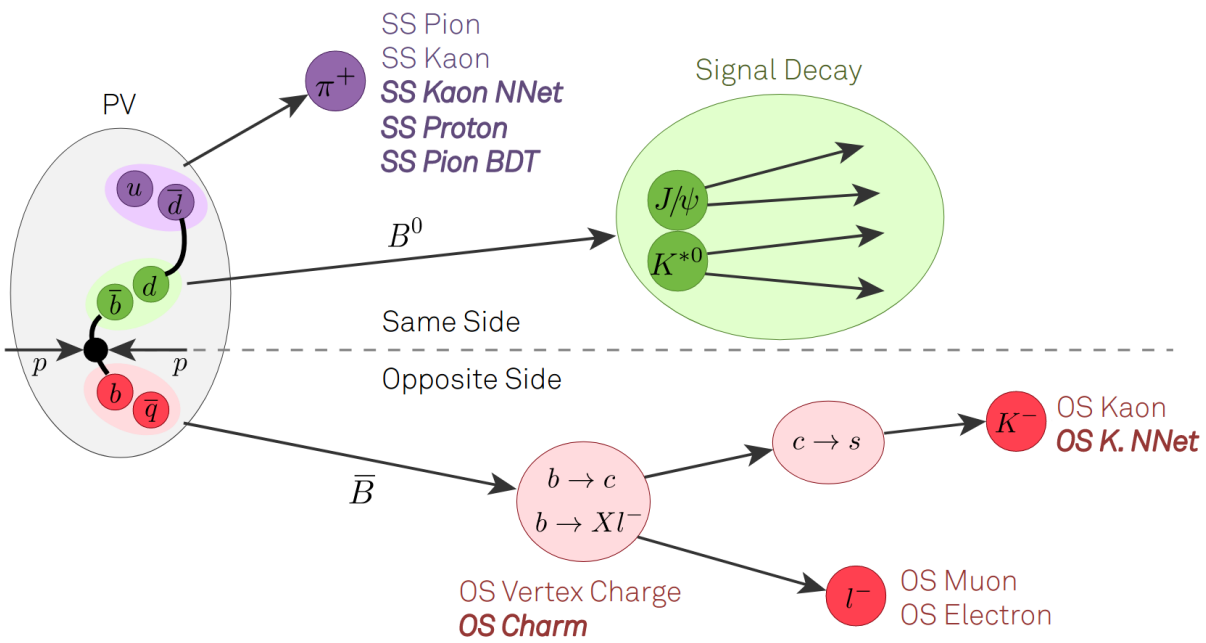
CP-violation in the decay

CP-violation in the mixing

$\Delta\Gamma_d$ negligible

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

$$(C_f)^2 + (S_f)^2 + \left(A_f^{\Delta\Gamma}\right)^2 = 1$$ Used as a cross-check



Same Side (SS) taggers

→ the flavour of the B^0 is determined based on the identification of the particles produced in the hadronisation of the signal b quark

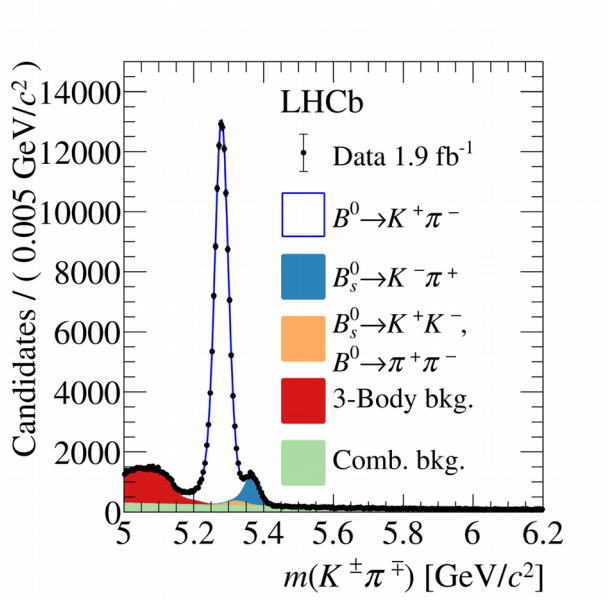
Opposite Side (OS) taggers

→ the flavour of the B^0 is determined based on the decay products of the other b hadron

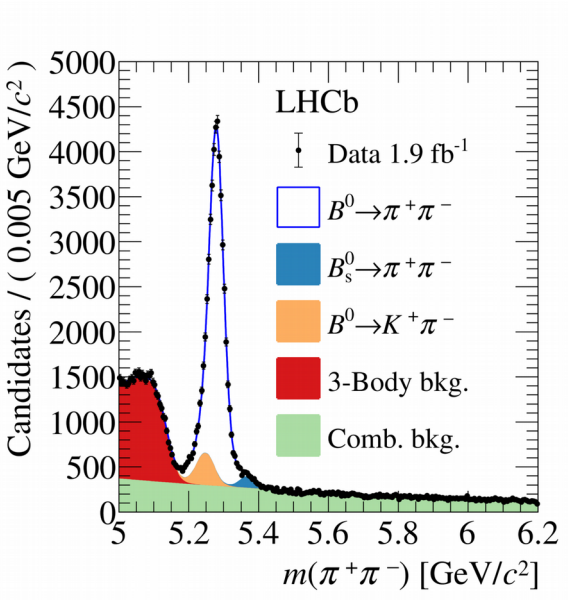
$B^0 \to K\pi$ decays used to recalibrated the OS and SSc combinations in the fit to correct for correlations between the algorithms

$B^0_{(s)} \to K\pi$, $B^0 \to K\pi$, $B^0 \to \pi^+\pi^-$, $B^0_s \to K^+K^-$ – Results

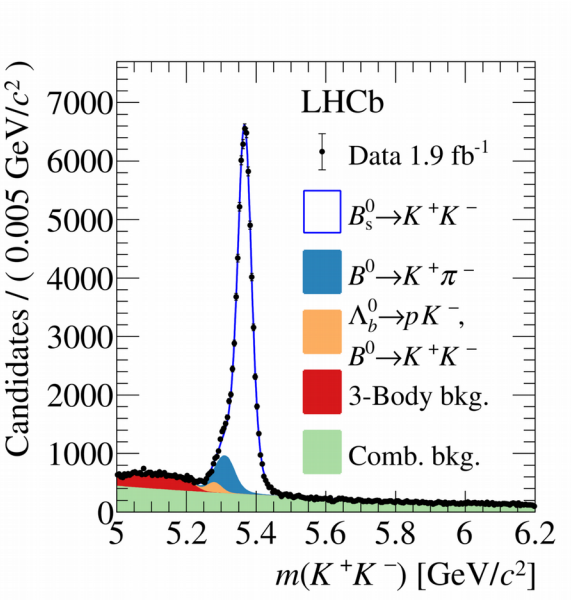
[JHEP 03 (2021) 075]



Signal yield 140340 +- 420 B^0
10580 +- 150 B^0_s



Signal yield 45620 +- 260 B^0



Signal yield 70310 +- 320 B^0_s

The CP-violation parameters are determined from a simultaneous fit to $B^0_{(s)} \to K\pi$, $B^0_s \to \pi^+\pi^-$, $B^0_s \to K^+K^-$ mass distributions, neutral B-meson decay times, tagging decisions and mis-tag probabilities

Time integrated CP-asymmetries ($B^0_{(s)} \to K\pi$) have to be corrected for selection asymmetries

→ determined using control samples

Corrected A_{CP} are

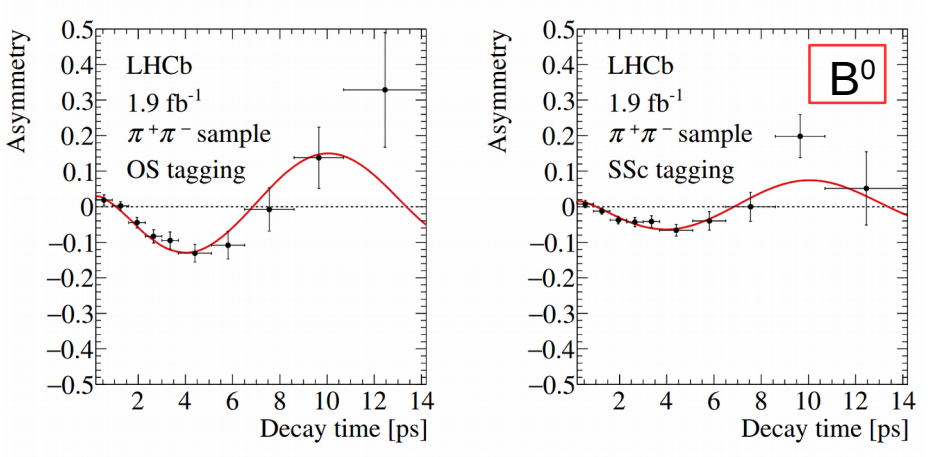
$$A_{CP}^{B^0} = -0.0824 \pm 0.0033 \pm 0.0033$$
$$A_{CP}^{B^0_s} = 0.236 \pm 0.013 \pm 0.011$$

Statistical Systematic

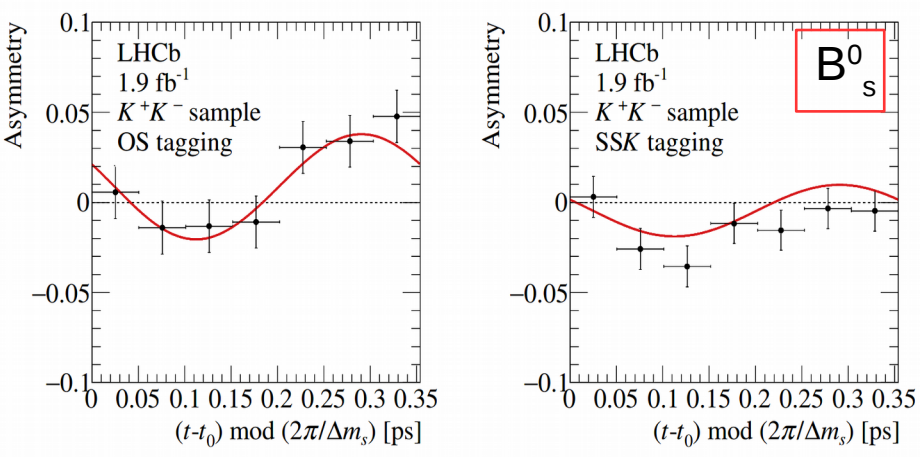
[JHEP 03 (2021) 075]

Assuming U-spin symmetry, Standard Model predictions can be tested with:

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



$$\begin{aligned} C_{\pi\pi} &= -0.320 \pm 0.038 \\ S_{\pi\pi} &= -0.672 \pm 0.034 \end{aligned}$$



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

$(C_{KK},\, S_{KK},\, \mathcal{A}^{\Delta\Gamma}_{KK})$ differ from (0, 0, 1) and $(C_{KK},\, S_{KK})$ differ from (0, 0) with a significance >6σ

First observation of time-dependent CP violation in B^0_s-meson decays

$$\sqrt{(C_{KK})^2 + (S_{KK})^2 + (\mathcal{A}^{\Delta\Gamma}_{KK})^2} = 0.93 \pm 0.08 \to$$ unitarity relation preserved

[JHEP 03 (2021) 075]

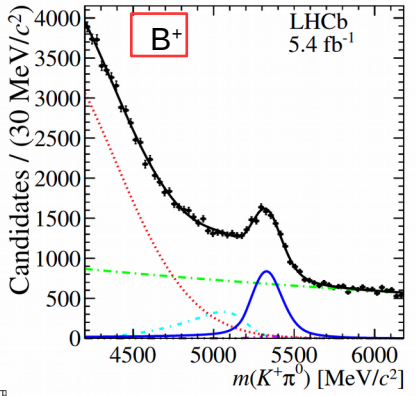
Summary

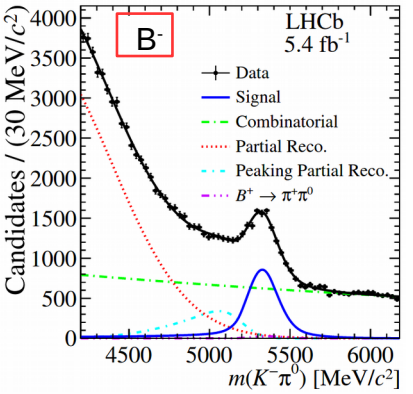
Challenging time-dependent and time-integrated analyses were performed to better understand CP violation in charmless 2-body B-meson decays

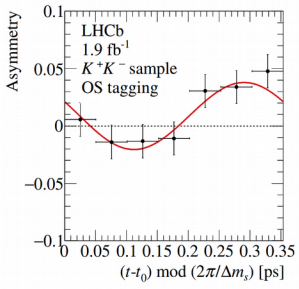
Measurement of CP violation in the decay $B^+ \to K^+\pi^0$

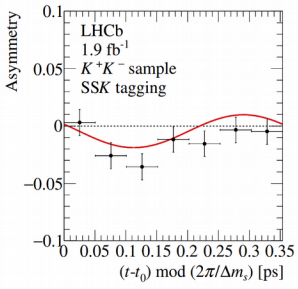
[Phys. Rev. Lett. 126, 091802 (2021)]

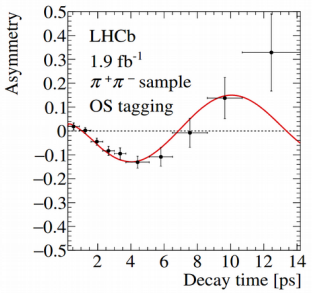
- **Most precise measurement** of $A_{CP}(B^+ \to K^+\pi^0)$
- Consistent with world average
- Confirms anomaly in $A_{CP}(B^+ \to K^+\pi^0) - A_{CP}(B^0 \to K^+\pi^-)$

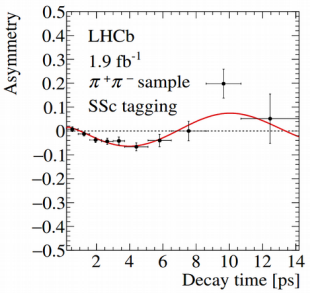












Observation of CP violation in 2-body $B^0_{(s)}$-meson decays to charged pions and kaons

[JHEP 03 (2021) 075]

- **Most precise measurement** from a single experiment of $C_{\pi\pi}$, $S_{\pi\pi}$, $A_{CP}(B^0)$, $A_{CP}(B^0_s)$
- **First observation** of time-dependent CP violation in B^0_s-meson decays
  - $(C_{KK},\ S_{KK})$ differ from (0, 0) with a significance >6σ