Measurements of B_s^0 oscillations and TD-CPV at LHCB

FPCP 2021 - Shanghai (Virtual)

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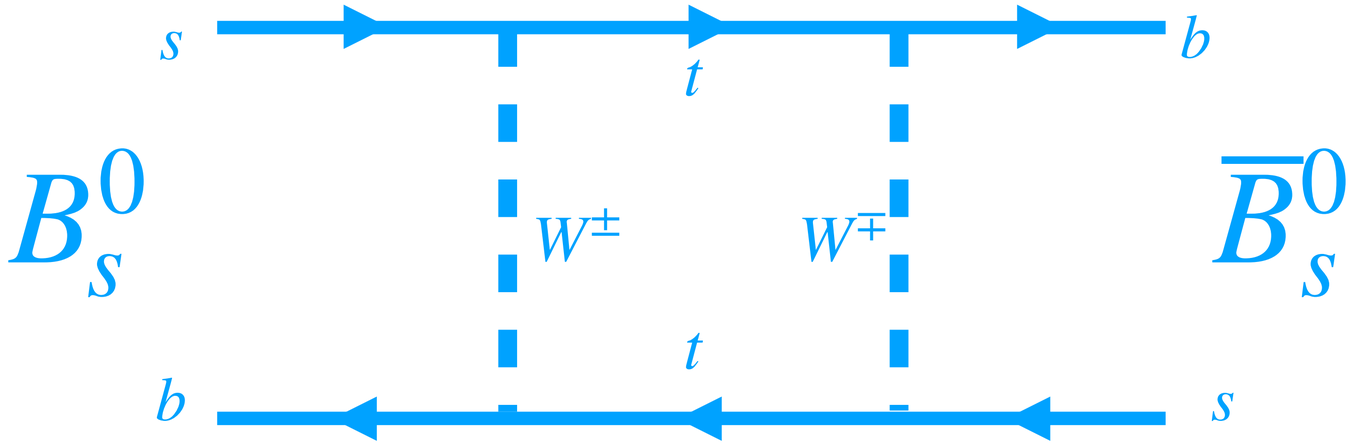
on behalf of LHCb

Outline

- Measurements of $B_s^0 - \bar{B}_s^0$ oscillations with flavour specific decays
  - $B_s^0 \to D_s^- \pi^+$ [arXiv:2011.12041]
  - $B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$ [JHEP 03 (2021) 137]
- Measurements of time dependent $\not{CP}$ in the $B_s^0 - \bar{B}_s^0$ system
  - $B_s^0 \to K^+ K^-$ [JHEP 03 (2021) 075]
  - $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ [JHEP 03 (2021) 137]

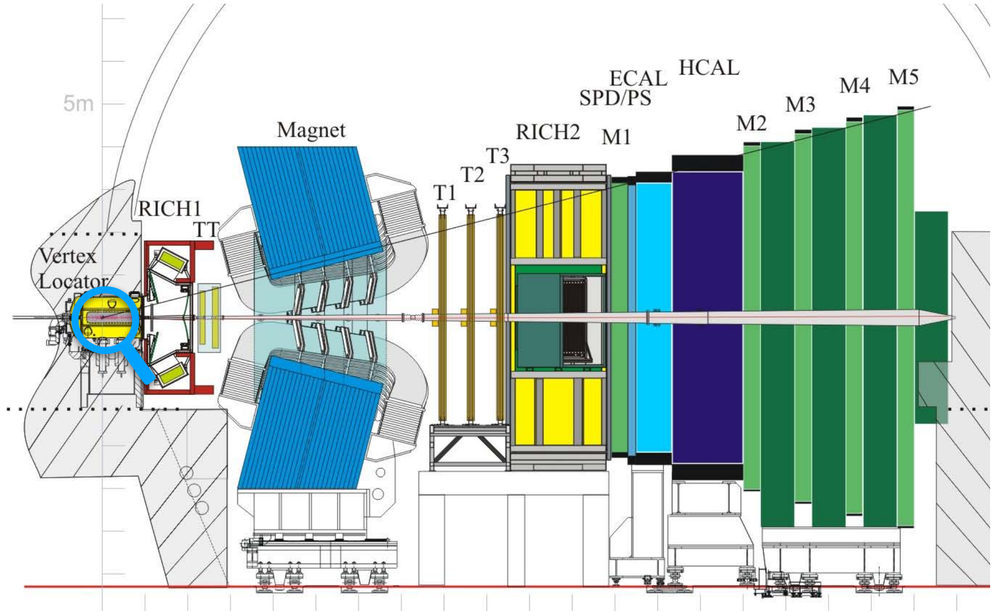
$B_s^0 - \bar{B}_s^0$ oscillations and TD-CPV

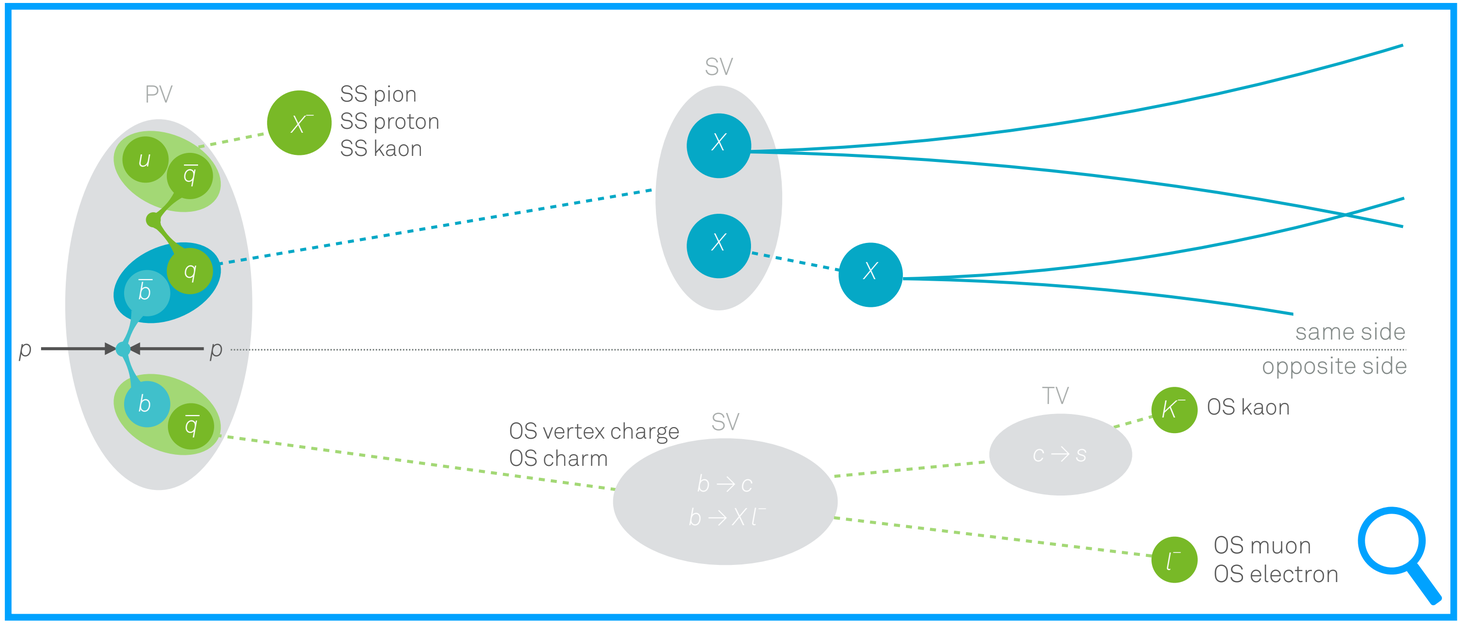
$B_s^0 - \bar{B}_s^0$ oscillations arise from virtual quark transitions



- Frequency proportional to the mass difference between the heavy and the light eigenstates $\sim \Delta m_s c^2/\hbar$
- Provide a second amplitude for the interference of $B_s^0 \to f$ and $B_s^0 \to \bar{B}_s^0 \to f$ processes

Flavour tagging





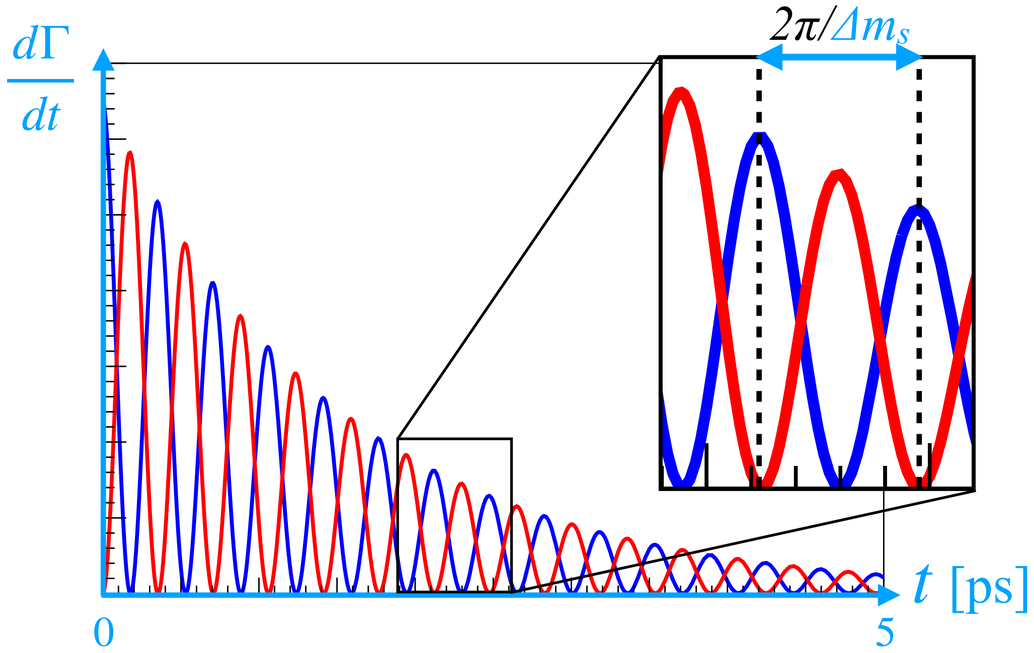
- Crucial input to measure the identity of the B_s^0 at production
- Combines informations from tracking and particle identification subsystems

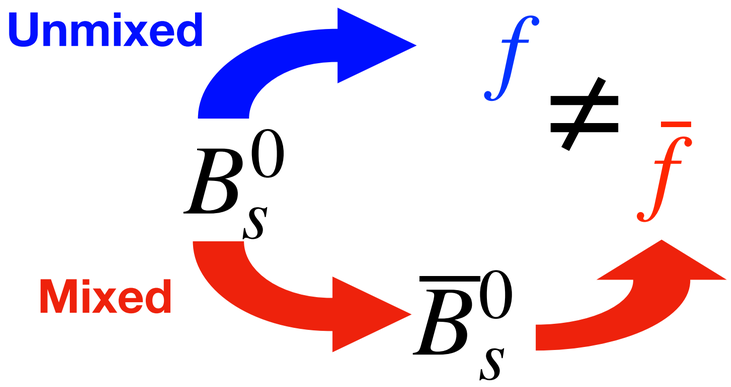
$B_s^0 - \bar{B}_s^0$ oscillations

[arXiv:2011.12041]

[JHEP 03 (2021) 137]

Measuring $B_s^0 - \bar{B}_s^0$ oscillations





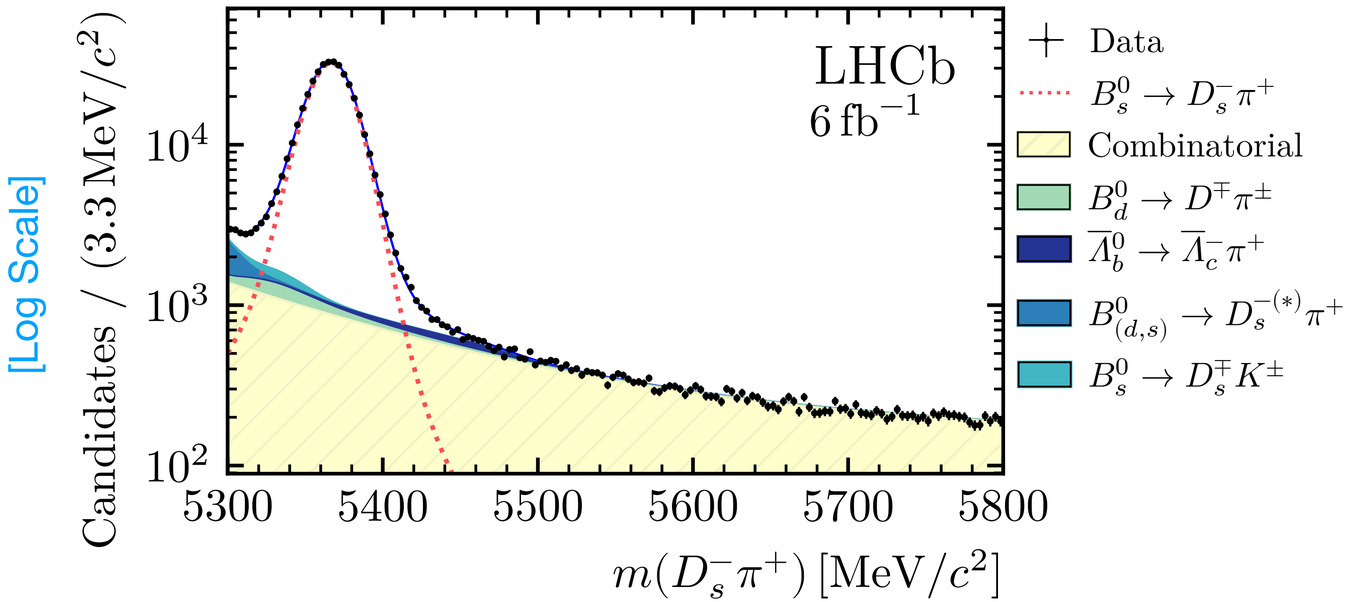
$$\frac{d\Gamma}{dt} \sim e^{-\Gamma_s t}\left\{\cosh\frac{\Delta\Gamma_s t}{2} \pm \cos\ \Delta m_s\, t\right\}$$

- Choose a flavour specific decay, i.e. $B_s^0 \to f$ but $B_s^0 \not\to \bar{f}$

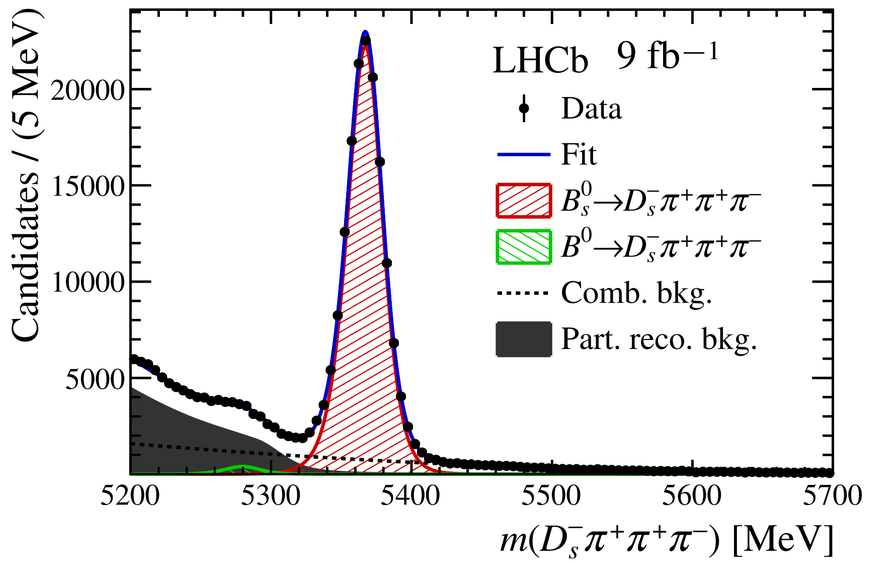
  → identity of the B_s^0 at decay from the charges of the decay products
- Oscillation frequency inversely proportional to the distance between two peaks in the B_s^0 decay time spectrum

Signal yields

$B_s^0 \to D_s^- \pi^+$ [arXiv:2011.12041]

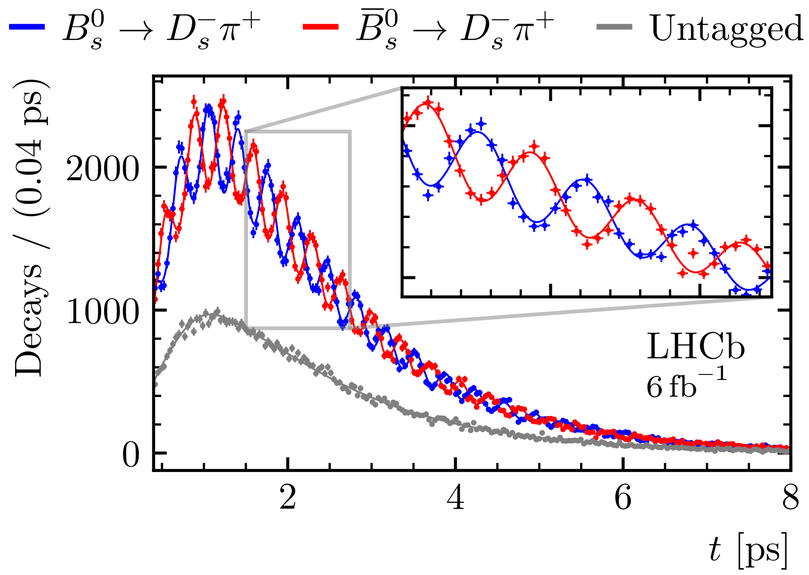


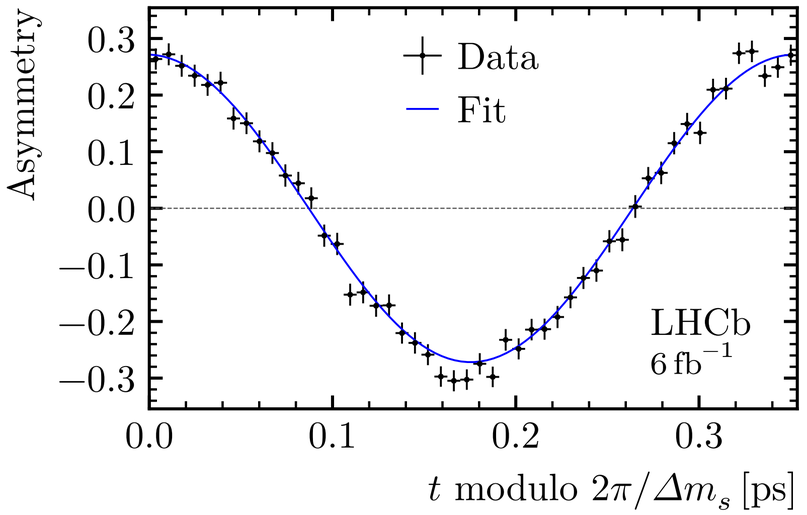
$B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$ [JHEP 03 (2021) 137]

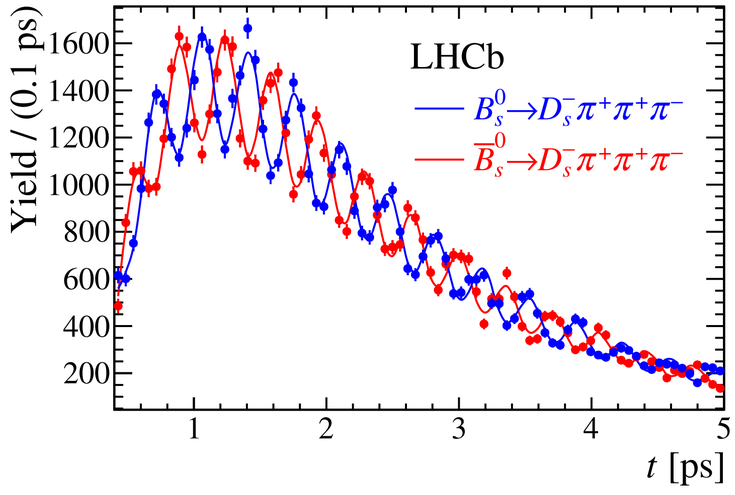


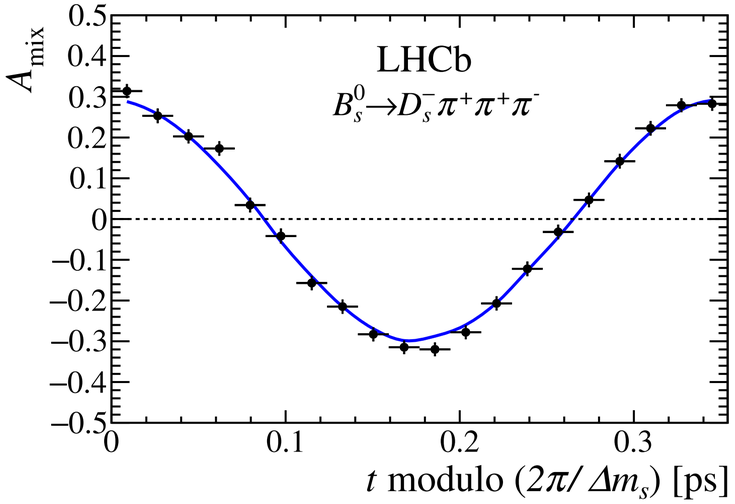
- Reconstructed 378 700 ± 700 (148 000 ± 400) signal $B_s^0 \to D_s^- \pi^+ (\pi^+\pi^-)$ decays in Run 2 (+ Run 1)
- $B_s^0 \to D_s^- \pi^+$ supersedes Run 1 measurement with 1 fb^{-1} [New J. Phys. 15 (2013) 053021]

Fit to the oscillations









$B_s^0 \to D_s^- \pi^+$ [arXiv:2011.12041]

$\Delta m_s = 17.7683$
± 0.0051(stat.)
± 0.0032 (syst.) ps^{-1}

$B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$ [JHEP 03 (2021) 137]

$\Delta m_s = 17.757$
± 0.007(stat.)
± 0.008 (syst.) ps^{-1}

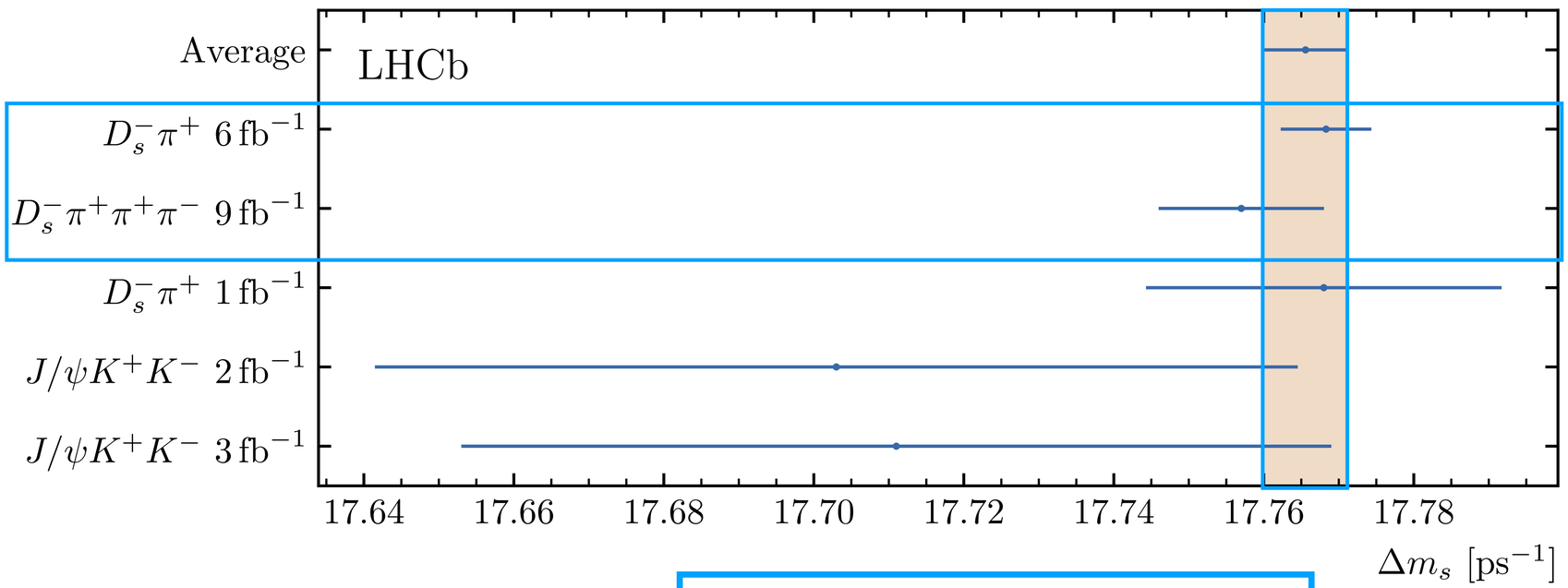
Tagging power ϵD^2

$B_s \to D_s^- \pi^+$: $(6.10 \pm 0.02 \pm 0.15)$ %

$B_s \to D_s^- \pi^+ \pi^+ \pi^-$: (6.52 ± 0.17) %

Comparable to performance in Run1 [JHEP 03 (2018) 059]

LHCb combination



$\Delta m_s = 17.7656 \pm 0.0057$ ps^{-1}

$B_s^0 \to D_s^-\pi^+$ [arXiv:2011.12041]

$\Delta m_s = 17.7683$
± 0.0051(stat.)
± 0.0032 (syst.) ps^{-1}

$B_s^0 \to D_s^-\pi^+\pi^+\pi^-$ [JHEP 03 (2021) 137]

$\Delta m_s = 17.757$
± 0.007(stat.)
± 0.008 (syst.) ps^{-1}

- Statistically independent samples
- Detector-related uncertainties fully correlated
- Uncertainties from fixed parameters negligible

Systematic uncertainties

Decay length scale ~0.002 ps^{-1}

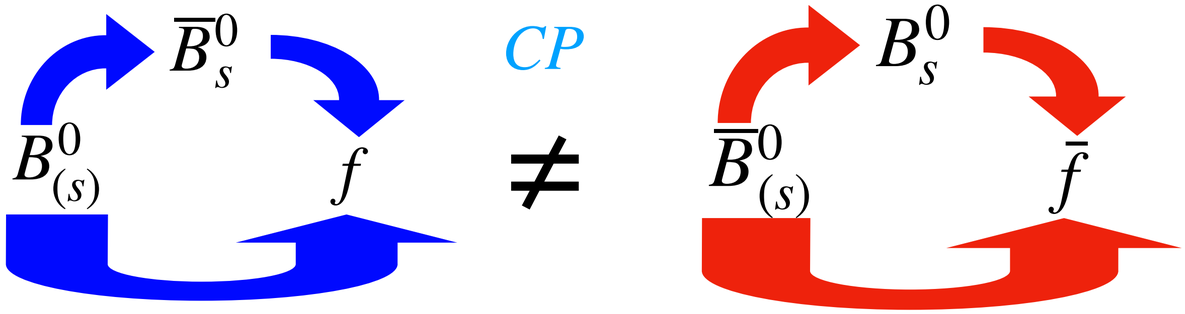
Momentum scale ~0.001 ps^{-1}

VELO alignment ~0.002 ps^{-1}
(~0.007 ps^{-1}) in $B_s \to D_s^-\pi^+(\pi^+\pi^-)$

Time-Dependent CP violation

[JHEP 03 (2021) 075]
[JHEP 03 (2021) 137]

Probing TD-CPV



$$\frac{d\Gamma}{dt} \sim e^{-\Gamma_s t}\left\{ \cosh\frac{\Delta\Gamma_s t}{2} \pm C_f \cos\Delta m_s t + A_f^{\Delta\Gamma} \sinh\frac{\Delta\Gamma_s t}{2} \mp S_f \sin\Delta m_s t \right\}$$

$f = \bar{f}$, e.g. $f = \bar{f} = K^+K^-$

- $C_f \neq 0$

  → $\not{CP}$ in the decay*
- $A_f^{\Delta\Gamma} \neq 0$, $S_f \neq 0$

  → $\not{CP}$ in the interference

$f \neq \bar{f}$, e.g. $f = D_s^- K^+(\pi^+\pi^-)$

- $C_f = -C_{\bar{f}}$

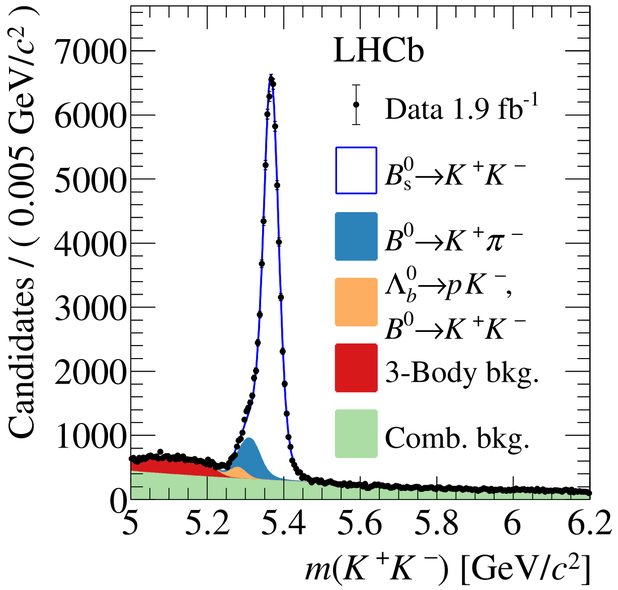
  → no $\not{CP}$ in the decay*
- $A_f^{\Delta\Gamma} \neq A_{\bar{f}}^{\Delta\Gamma}$, $S_f \neq -S_{\bar{f}}$

  → $\not{CP}$ in the interference

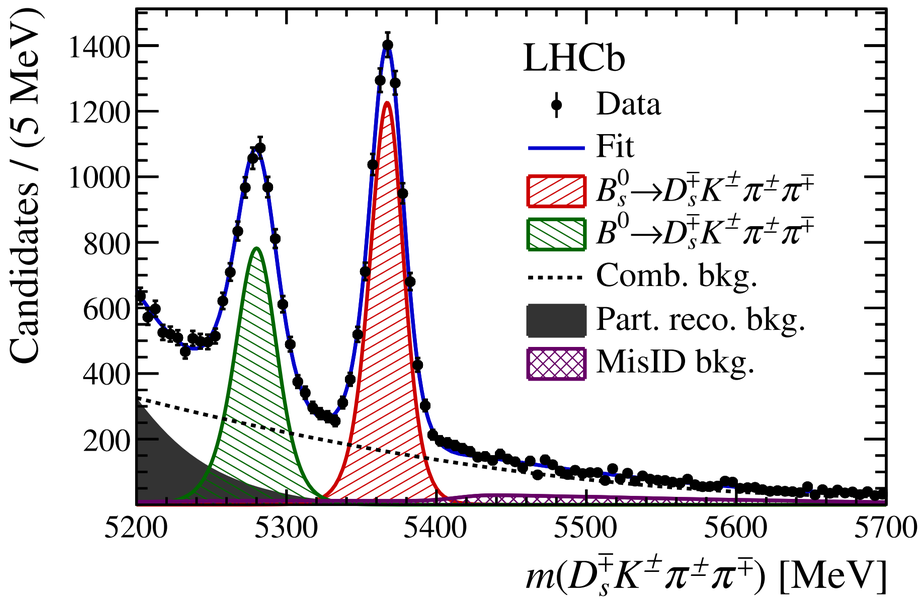
* no $\not{CP}$ in mixing is assumed

Signal yields

$B_s^0 \to K^+K^-$ [JHEP 03 (2021) 075]



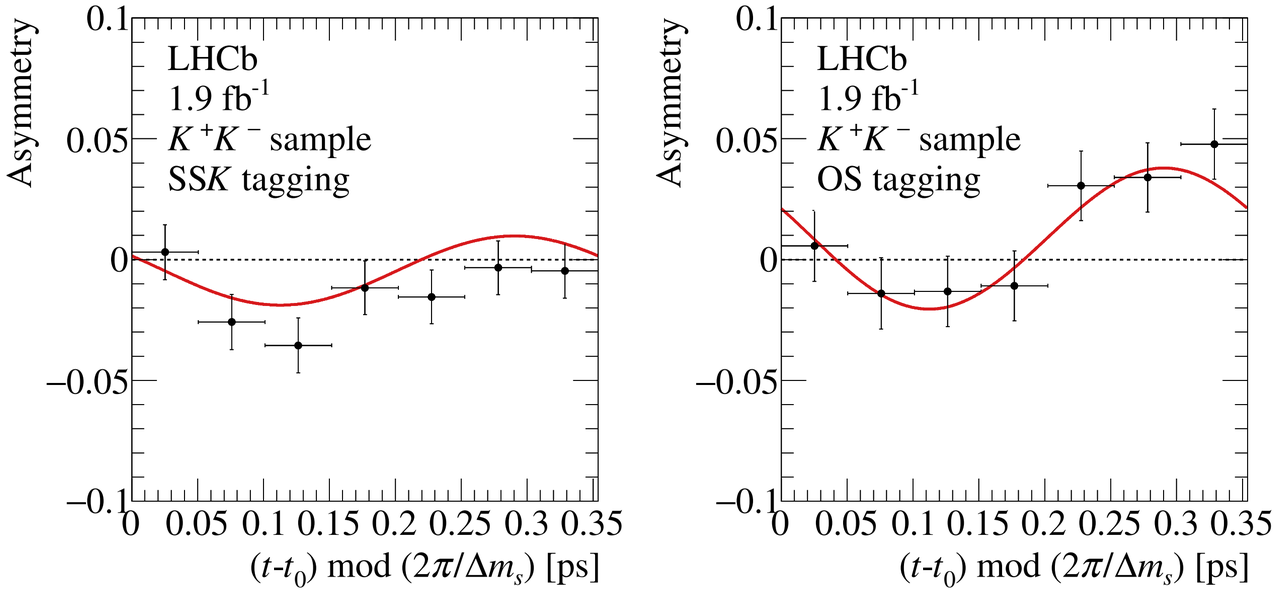
$B_s^0 \to D_s^- K^+\pi^+\pi^-$ [JHEP 03 (2021) 137]



- Reconstructed 70 310 ± 320 signal $B_s^0 \to K^+K^-$ decays in Run 2 and 7500 ± 100 signal $B_s^0 \to D_s^- K^+\pi^+\pi^-$ decays in Run 1 + 2

TD-CP asymmetries

$B_s^0 \to K^+K^-$ [JHEP 03 (2021) 075]



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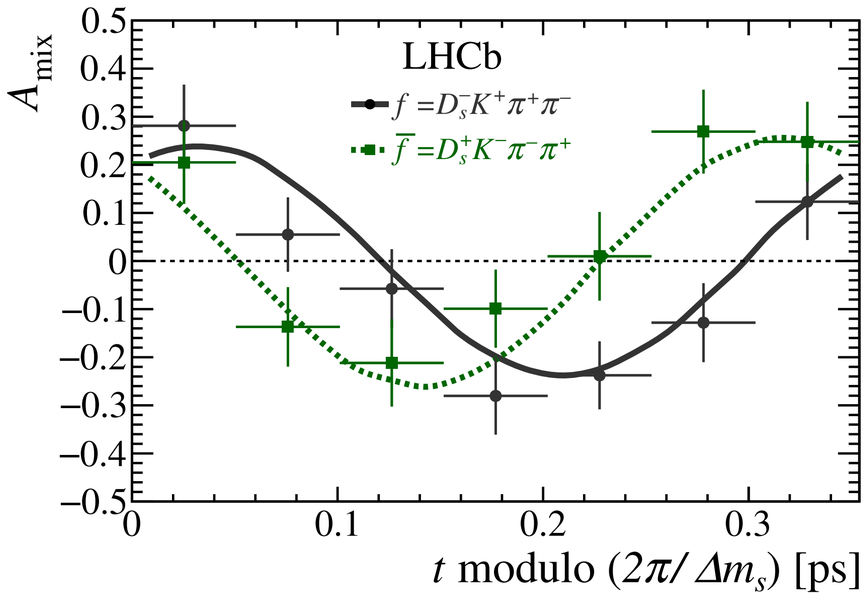


6.5σ observation

$$\begin{aligned} C_{KK} &= 0.164 \pm 0.034 \pm 0.014, \\ S_{KK} &= 0.123 \pm 0.034 \pm 0.015, \\ \mathcal{A}_{KK}^{\Delta\Gamma} &= -0.83 \pm 0.05 \pm 0.09, \end{aligned}$$

Run 2

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

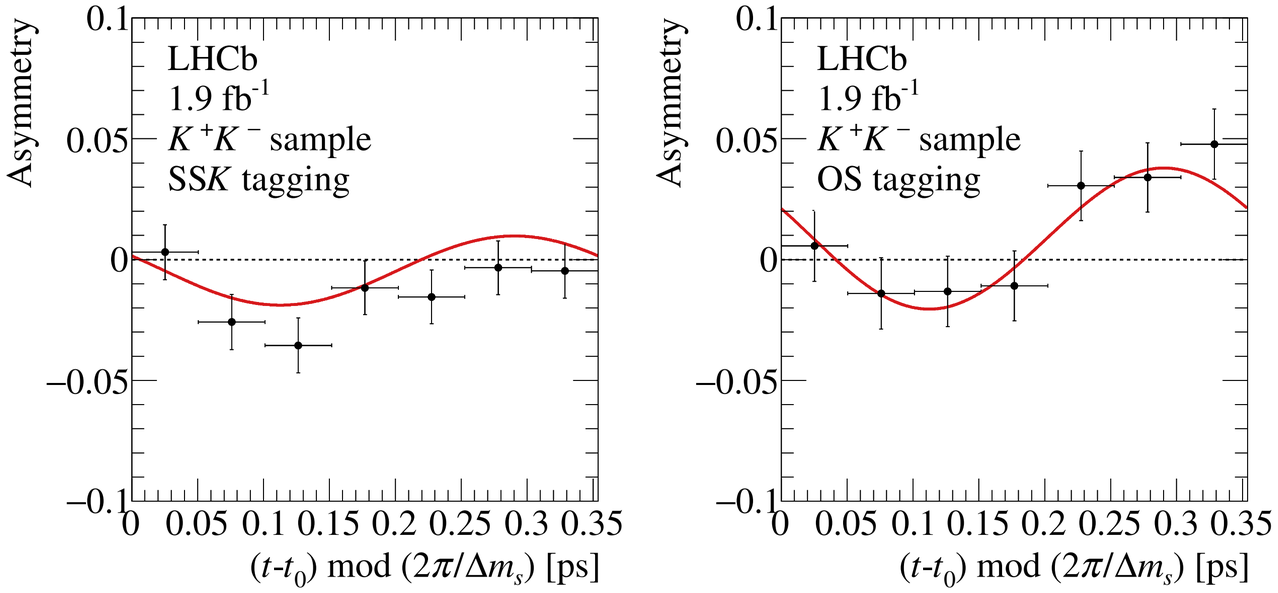
combined with Run 1

4.4σ evidence

$$\begin{aligned} C_f &= 0.631 \pm 0.096 \pm 0.032 \\ A_f^{\Delta\Gamma} &= -0.334 \pm 0.232 \pm 0.097 \\ A_{\bar{f}}^{\Delta\Gamma} &= -0.695 \pm 0.215 \pm 0.081 \\ S_f &= -0.424 \pm 0.135 \pm 0.033 \\ S_{\bar{f}} &= -0.463 \pm 0.134 \pm 0.031 \end{aligned}$$

TD-CP asymmetries

$B_s^0 \to K^+K^-$ [JHEP 03 (2021) 075]



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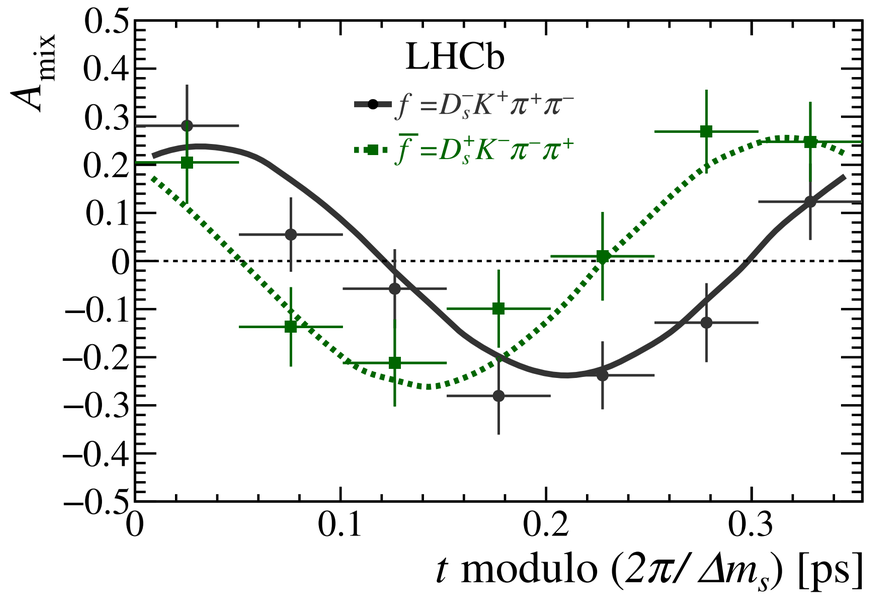

- $B_s^0 \to K^+K^-$ results crosschecked with “simultaneous” and “per-event” methods in Run 2
- $B_s^0 \to D_s^- K^+\pi^+\pi^-$ measurement also performed through time-dependent amplitude analysis (direct extraction of CKM phase γ)
- More details about interpretation in terms of CKM phases in Wenbin Qian’s talk (Thursday)

Conclusions

- $B_s^0 - \bar{B}_s^0$ system is an ideal laboratory to study time dependent $\not{CP}$
  - $B_s^0 \to K^+K^-$ [JHEP 03 (2021) 075]: first observation of TD-$\not{CP}$ in the B_s^0
  - $B_s^0 \to D_s^-K^+\pi^+\pi^-$ [JHEP 03 (2021) 137]: 4.4σ evidence of TD-$\not{CP}$
- Enabled by LHCb excellent reconstruction of $B_s^0 - \bar{B}_s^0$ oscillations
  - $B_s^0 \to D_s^-\pi^+(\pi^+\pi^-)$ [arXiv:2011.12041]: combination of LHCb measurements of the B_s^0 mixing frequency Δm_s

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Thank you for your attention!