Time-dependent CP-violation measurements at LHCb

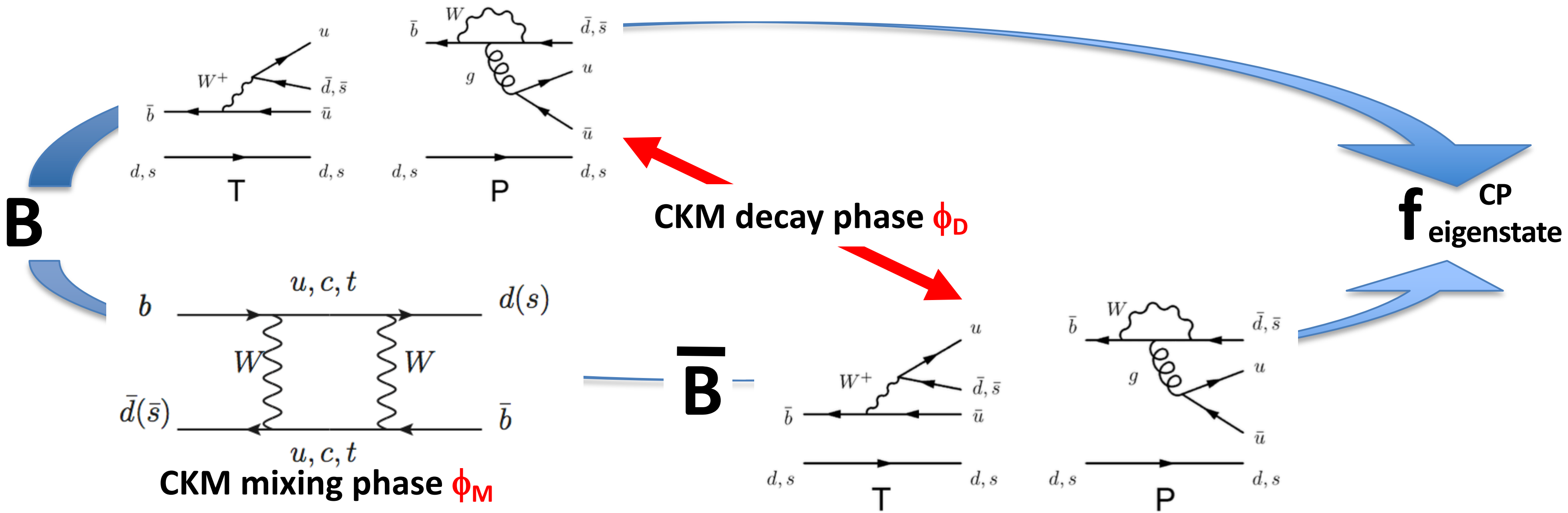
Stefano Perazzini, on behalf of LHCb Collaboration

BEAUTY 2020, CP violation and lifetimes – 22nd September 2020

Outline

- Physics motivations
- The LHCb detector
- Key ingredients for time-dependent measurements
- Recent LHCb results
  - Time-dependent CPV in $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ (LHCb-PAPER-2020-030) NEW
  - Time-dependent CPV in $B_{(s)}^0 \to h^+ h'^-$ (h = K, π) (LHCb-PAPER-2020-029) NEW
- Conclusions

Time-dependent CPV



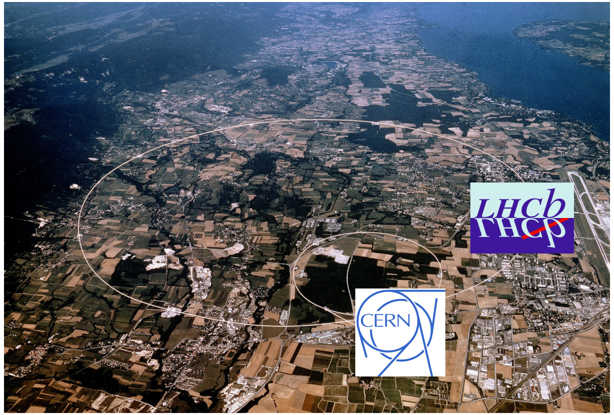
$$A(t) = \frac{-C_f\cos(\Delta m\, t)+S_f\sin(\Delta m\, t)}{\cosh\left(\frac{\Delta\Gamma}{2}t\right)+A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}t\right)}$$

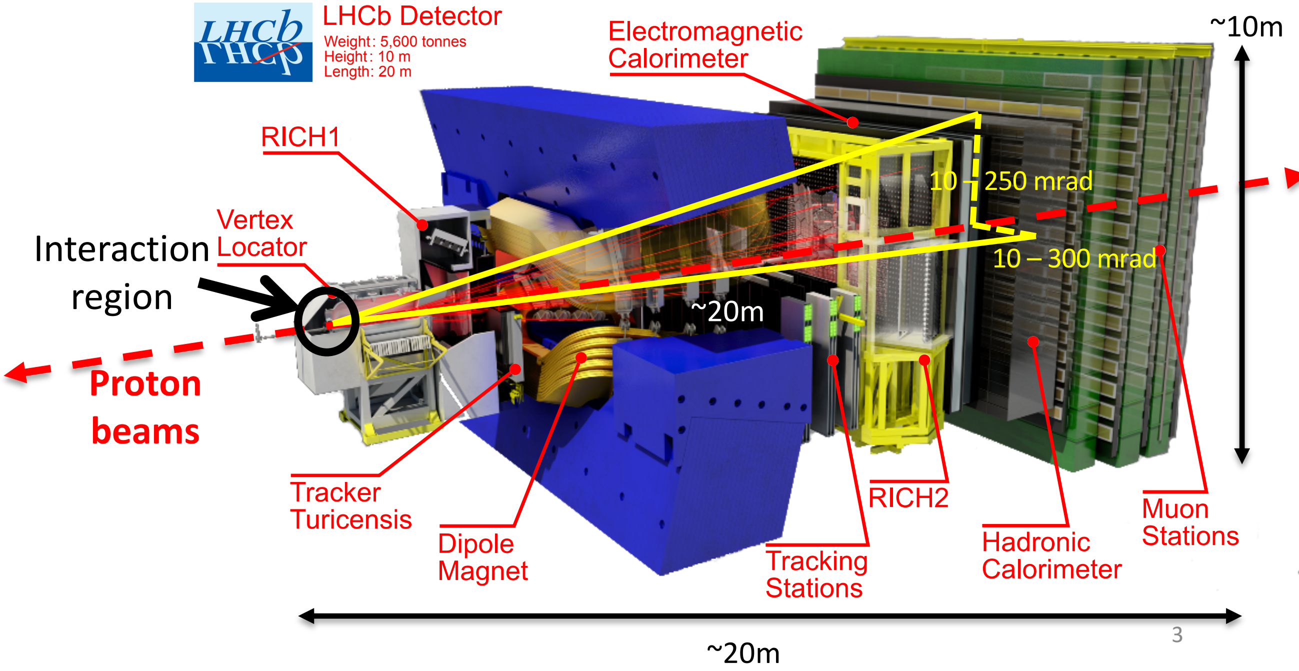
$$C_f^2 + S_f^2 + A_f^2 = 1$$

- C_f (ϕ_D) → CPV from CKM phase in decay
- S_f (ϕ_D,ϕ_M) → CPV from interference between mixing and decay
- Physics beyond Standard Model can appear as virtual contributions in the penguin and box diagrams

The LHCb detector

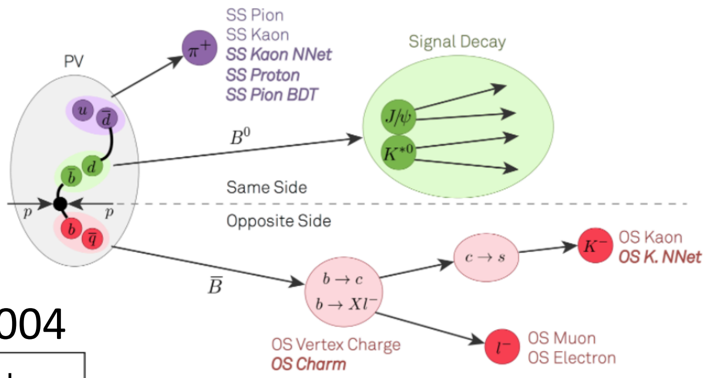
- LHCb is a forward spectrometer
  - High geometrical efficiency to collect $b\bar{b}$ and $c\bar{c}$ quark pairs
  - Great time resolution (σ_t ~ 45 fs), momentum resolution ($\delta p/p$ ~ 0.4-0.6%), PID performances (RICH)



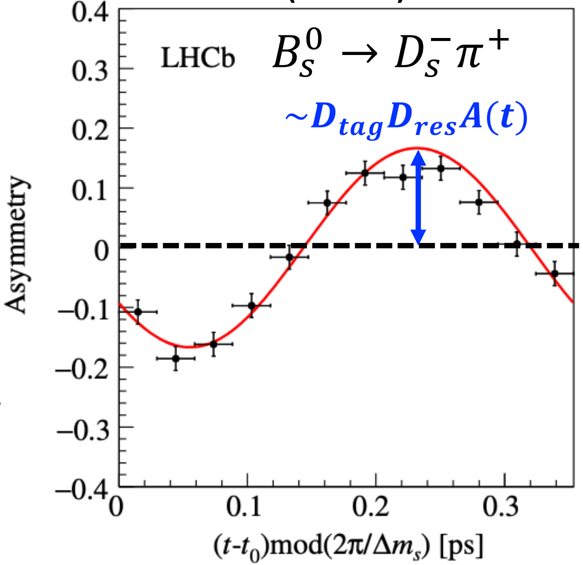


Key ingredients of TD measurements

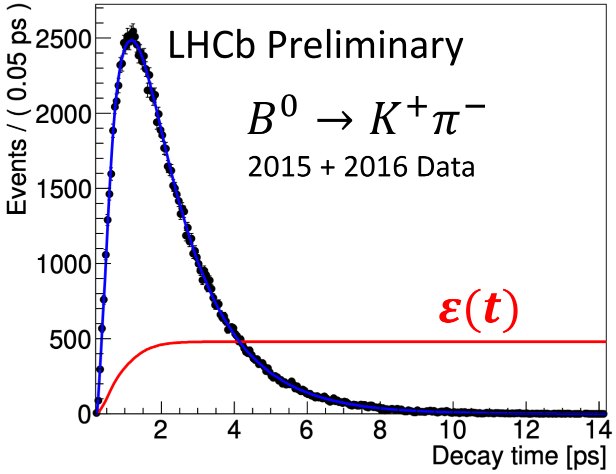
- Determination of B flavour at production
  - Dilution factor $D_{tag} = 1 - 2\omega$ of the asymmetry
  - ω = mistag fraction
- Decay time resolution
  - Dilution factor $D_{res} = e^{-\frac{\sigma_t^2 \Delta m^2}{2}}$
  - σ_t = decay-time resolution
  - Very important for B_s^0
- Decay-time efficiency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



PRD98(2018)032004



LHCb-PAPER-2020-029

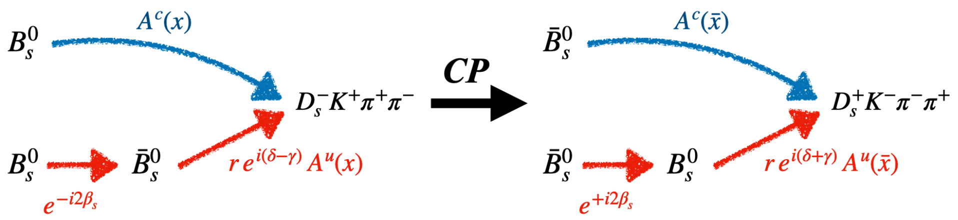


CP-violation in $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ decays (LHCb-PAPER-2020-030)

To be posted on arXiv soon

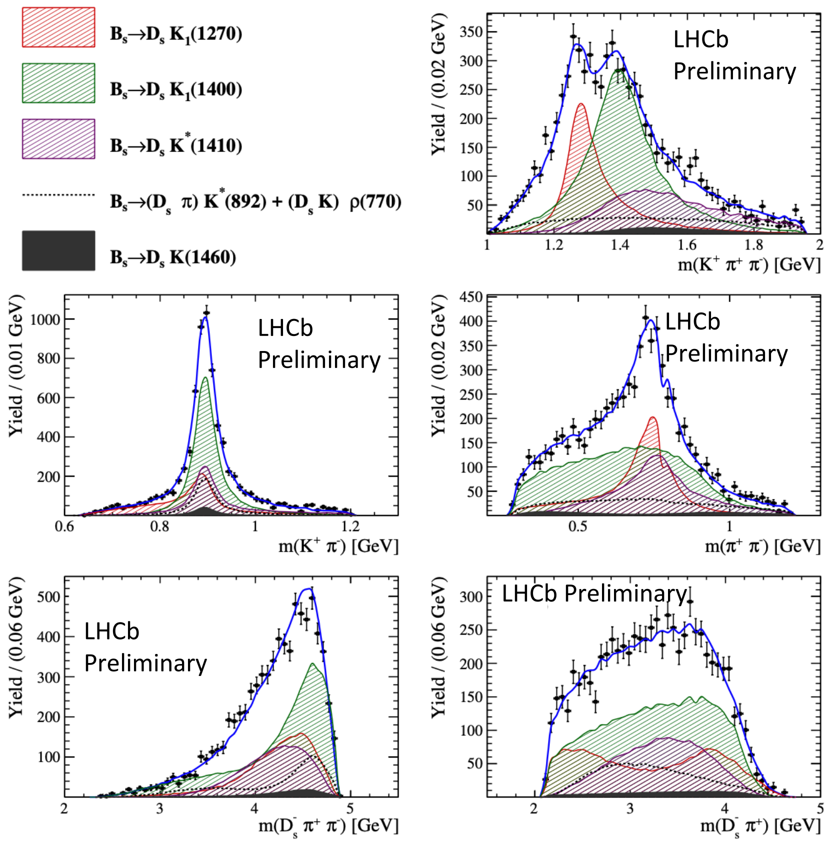
CP-violation in $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ decays

- Study interference between $b \to c$ and $b \to u$ transitions achieved through $B - \bar{B}$ mixing



- Four decay rates with CPV parameters sensitive to CKM angle γ and B_s^0 mixing phase ϕ_s

- Strong phases in $A^u(x)$ and $A^c(x)$ in the decay depends on 5D phase space of $D_s^- K^+ \pi^+ \pi^-$ final state
  - Sensitivity on γ and ϕ_s change over the phase space
  - Perform both model-dependent and model-independent analysis over the phase space

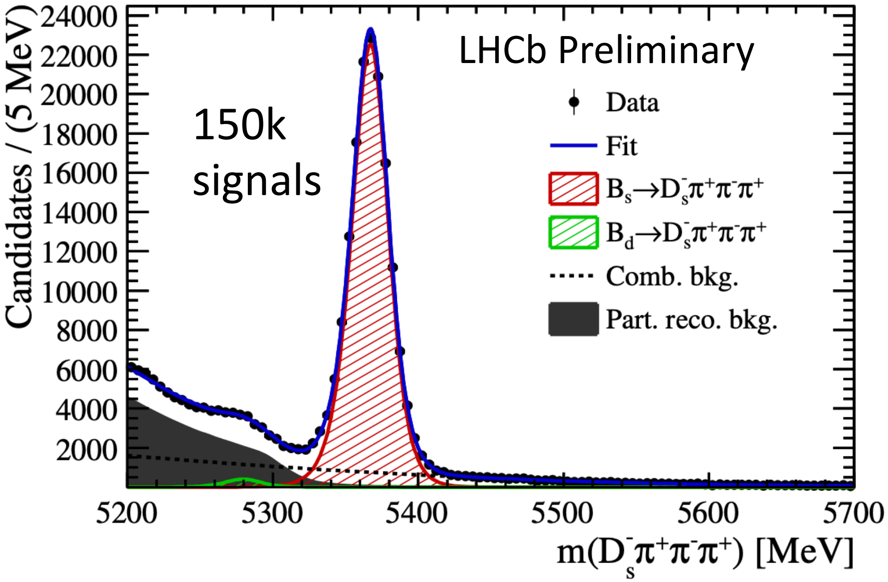


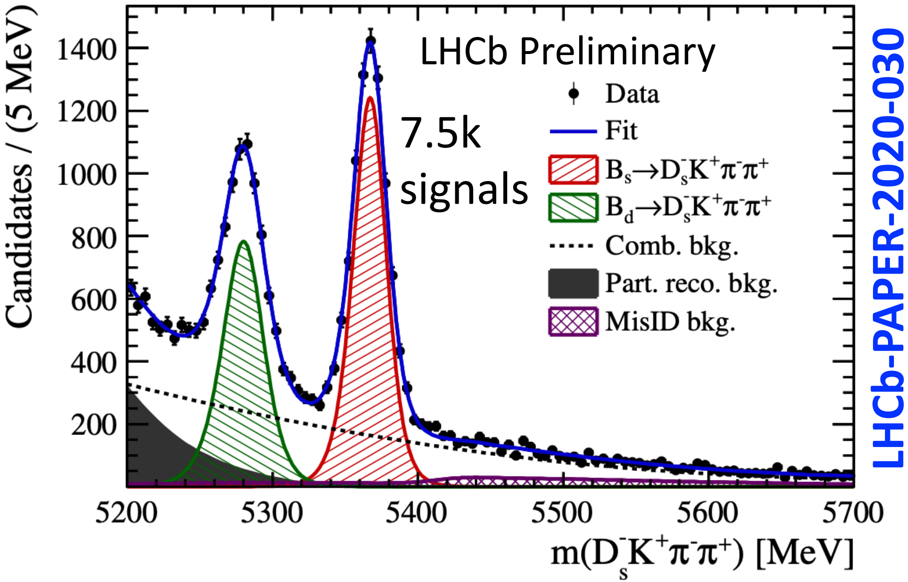
LHCb-PAPER-2020-030

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

- Analysis based on full LHCb dataset → ~9 fb^{-1}
- Natural calibration sample is $B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$ decay
  - Used for flavour tagging and decay-time efficiency
  - Large statistics allow to perform precise measurement of B_s^0 mixing frequency Δm_s
  - Use mass fit to subtract background and then perform sFit [arXiv:0905.0724]

LHCb-PAPER-2020-030





LHCb-PAPER-2020-030

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

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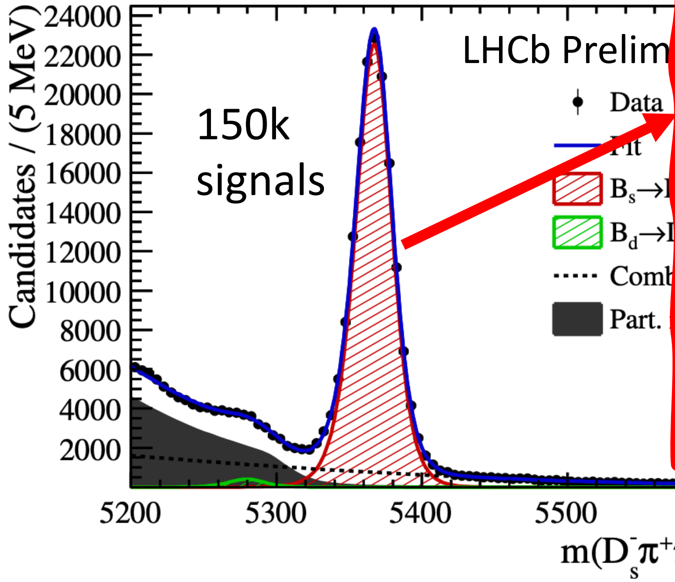
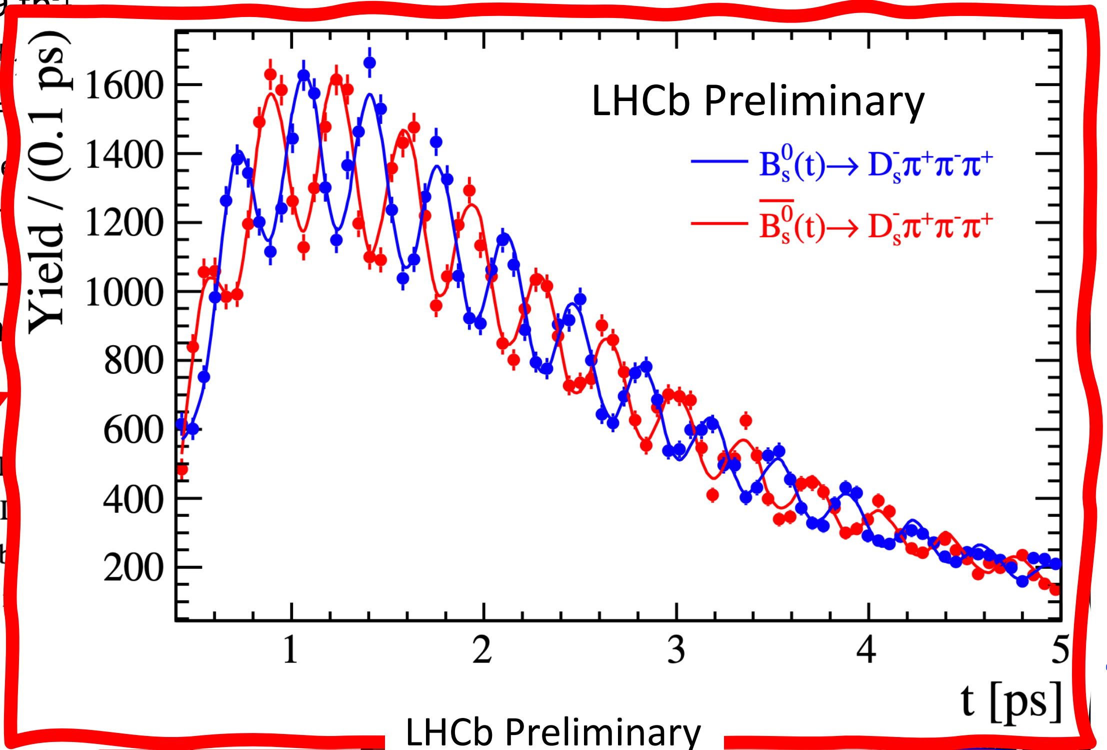




LHCb Preliminary

$\Delta m_s = (17.757 \pm 0.007 \pm 0.008)$ ps^{-1}

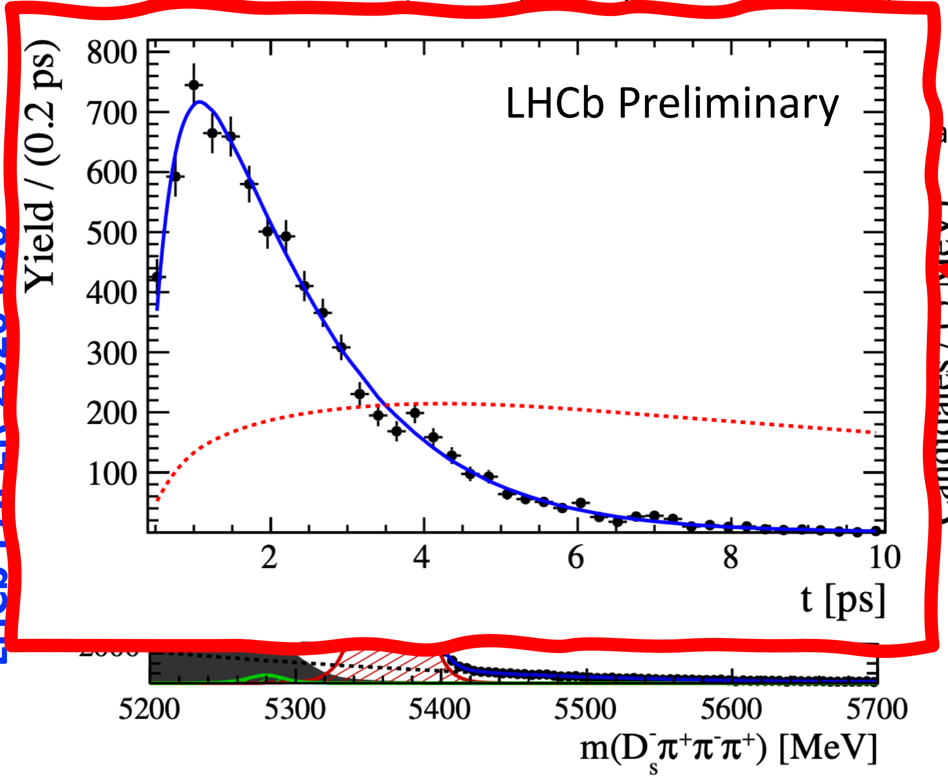
LHCb-PAPER-2020-030

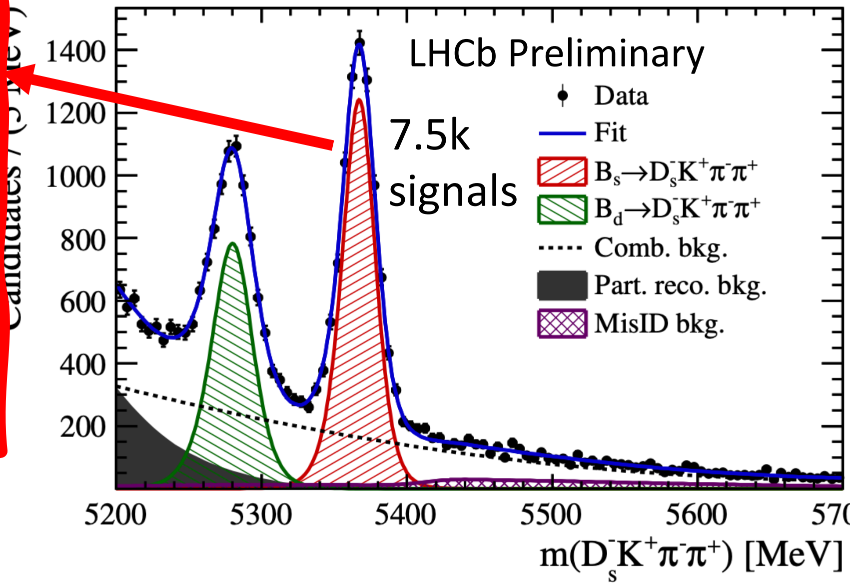
CP-violation in $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ decays

- Analysis based on full LHCb dataset → ~9 fb^{-1}
- Natural calibration sample is $B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$ decay

mixing frequency Δm_s

arXiv:0905.0724]





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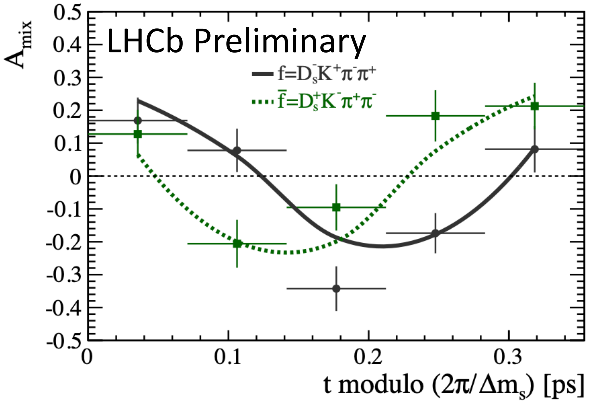
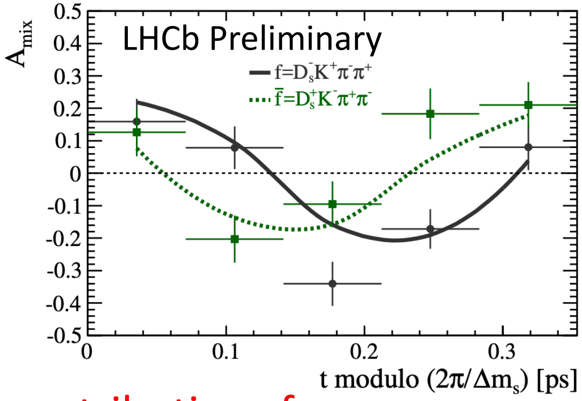
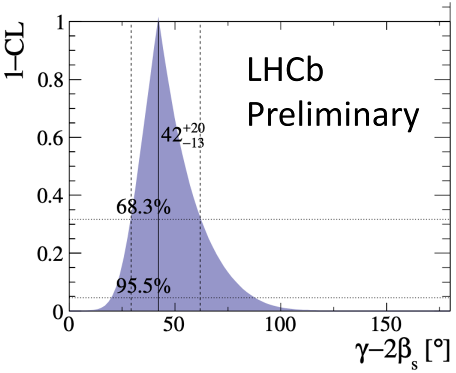
CP-violation in $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ decays

Model independent fit | LHCb-PAPER-2020-030 | **Model-dependent fit**





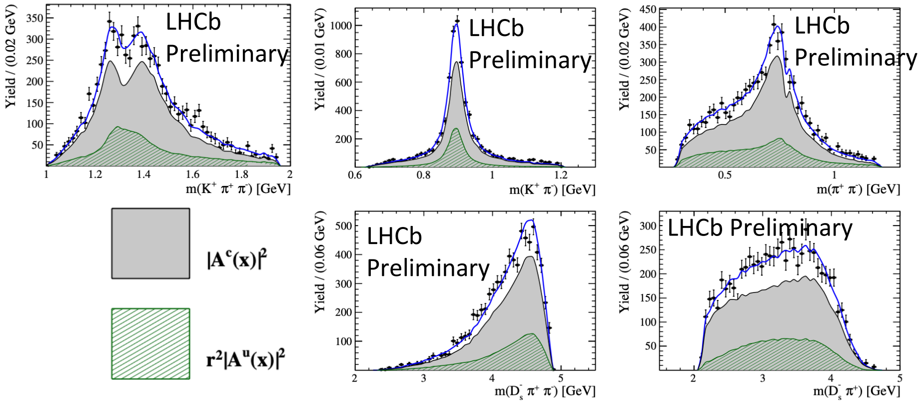
Use CPV parameters to determine γ



LHCb Preliminary

Fit Parameter	Value
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	$-0.424 \pm 0.135 \pm 0.033$
$S_{\bar{f}}$	$-0.463 \pm 0.134 \pm 0.031$

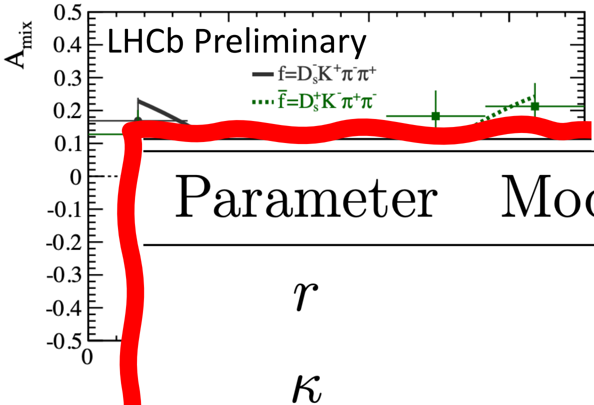
Different contributions from $b \to c$ and $b \to u$ transitions

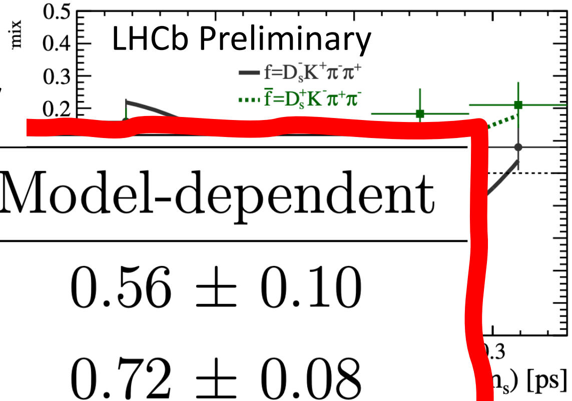


CP-violation in $B_s^0 \to D_s^- K^+ \pi^+ \pi^-$ decays

LHCb-PAPER-2020-030

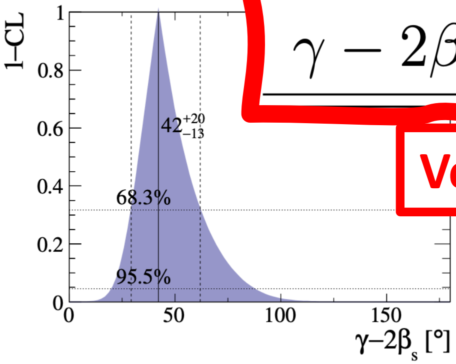
Model independent fit | **Model-dependent fit**



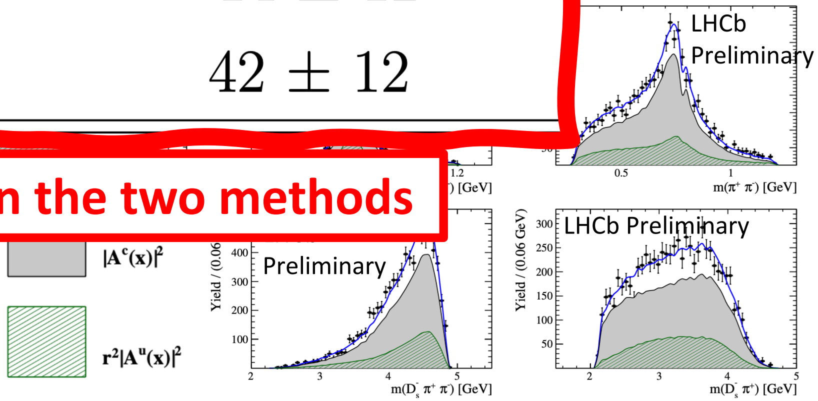


LHCb Preliminary

Parameter	Model-independent	Model-dependent
r	$0.47^{+0.08}_{-0.08}$	0.56 ± 0.10
κ	$0.88^{+0.12}_{-0.20}$	0.72 ± 0.08
δ [°]	-6^{+10}_{-13}	-14 ± 12
$\gamma - 2\beta_s$ [°]	42^{+20}_{-13}	42 ± 12



$S_{\bar{f}}$ $-0.463 \pm 0.134 \pm 0.031$



Very good agreement between the two methods

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

(LHCb-PAPER-2020-029)

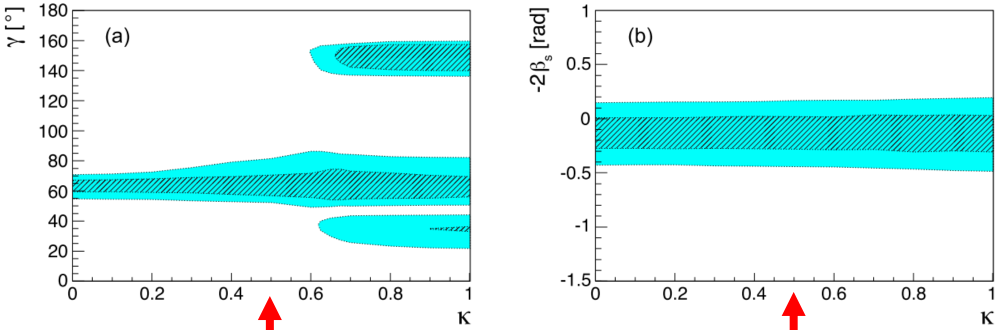
To be posted on arXiv soon

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

- A rich set of physics processes participates to the $B^0_s \to h^+ h'^-$ decays
  - Tree and penguin decay topologies
- CPV observables are sensitive to CKM angles γ/ϕ_3 and α/ϕ_2, and $B^0_{(s)}$ mixing phases ϕ_s and ϕ_d
  - presence of loop diagrams introduce hadronic uncertainties but gives sensitivity to physics beyond SM

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

Phys. Lett. B741 (2015) 1



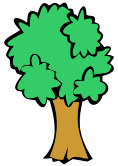
$$\gamma = (63.5^{+7.2}_{-6.7})^\circ,$$

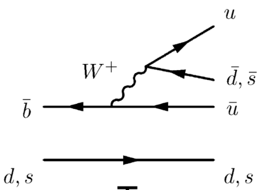
$$-2\beta_s = -0.12^{+0.14}_{-0.16}\ \text{rad}.$$

Up to 50% non factorisable U-spin breaking effects

Compatible with tree-level determinations

Numbers based on Run1-only results





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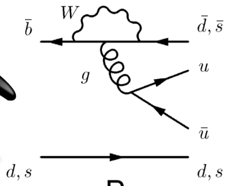

P

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

- Analysis based on 2015 + 2016 data → ~ 1.9 fb^{-1}
  - Time-dependent CPV in $B^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$
  - Time-integrated CPV in $B^0 \to K^+\pi^-$ and $B_s^0 \to K^-\pi^+$
- 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

- CP asymmetries of $B^0 \to K^+\pi^-$ and $B^0_s \to K^-\pi^+$ 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 $D^+ \to K^0_S\pi^+$ decays

LHCb Preliminary

$$
\boxed{
\begin{aligned}
A_{CP}^{B^0} &= -0.0824 \pm 0.0033 \pm 0.0033 \\
A_{CP}^{B^0_s} &= 0.236 \pm 0.013 \pm 0.011,
\end{aligned}
}
$$

In agreement with previous determinations from LHCb, BaBar, Belle and CDF

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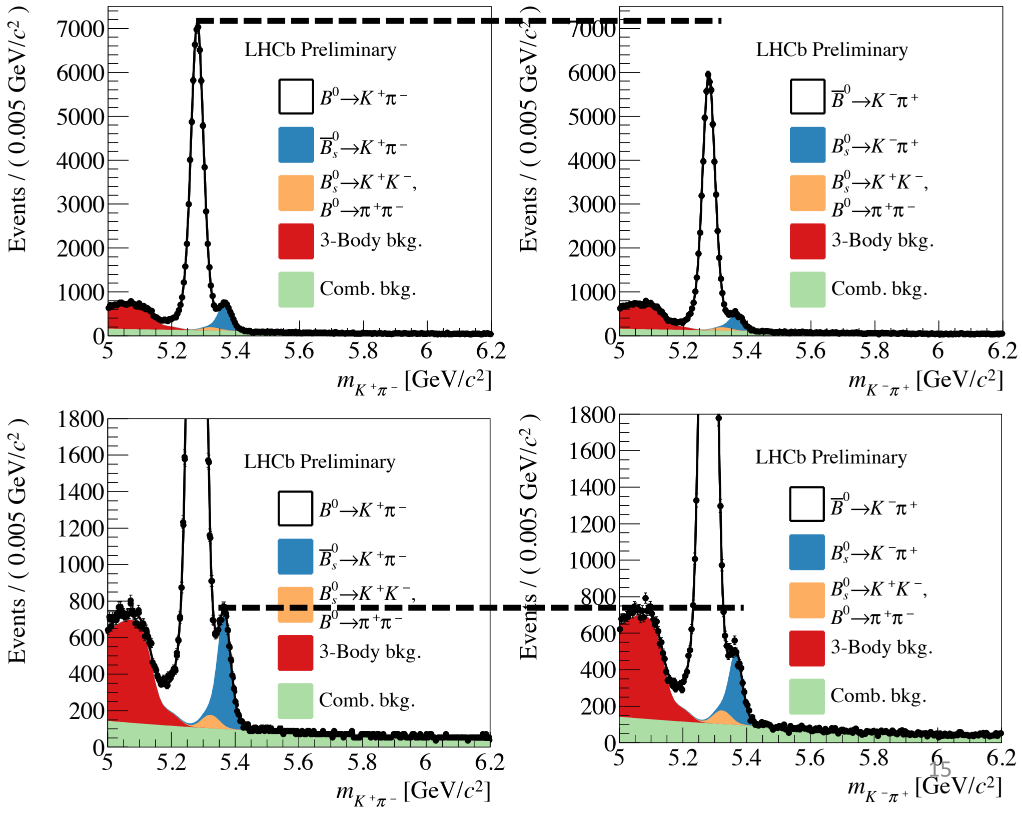
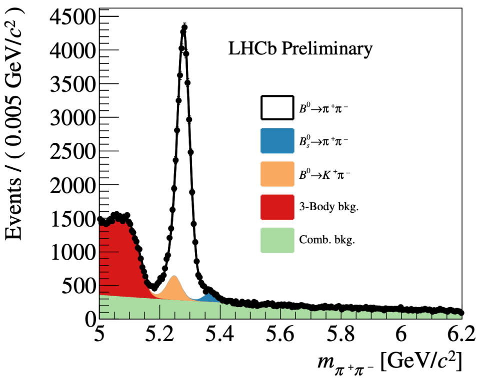
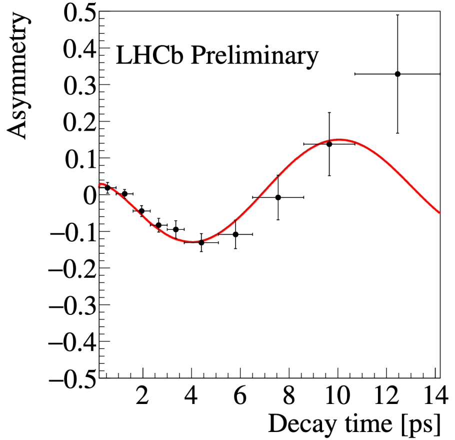


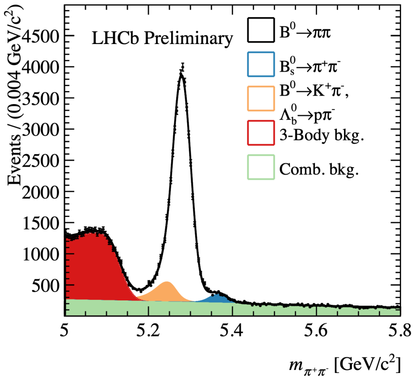
CP-violation in $B^0_{(s)} \to h^+ h'^-$ decays

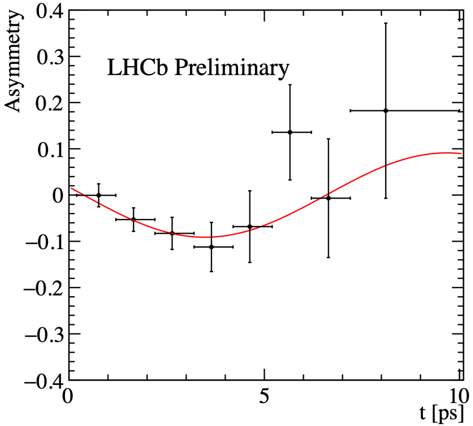
Simultaneous method





Per-event method





LHCb-PAPER-2020-029

LHCb Preliminary

Simultaneous method

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

Per-event method

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

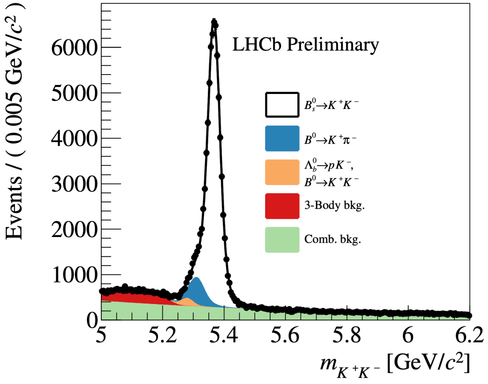
Compatibility is measured with pseudoexperiments to be below 1σ

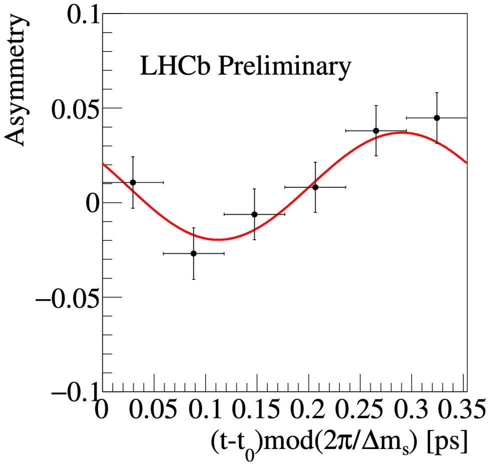
In agreement with previous determinations

LHCb-PAPER-2020-029

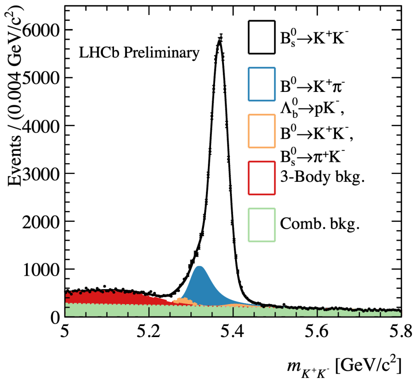
CP-violation in $B^0_{(s)} \to h^+ h'^-$ decays

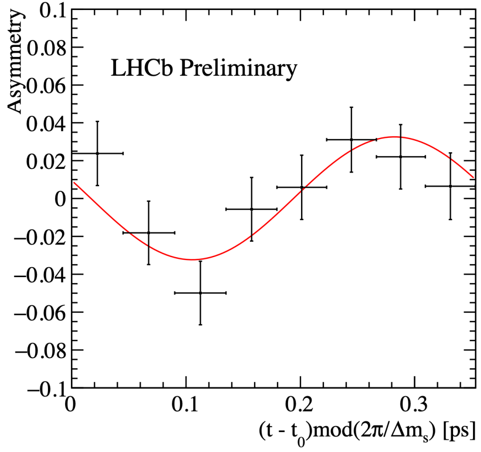
Simultaneous method





Per-event method





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LHCb Preliminary

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

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

LHCb-PAPER-2020-029

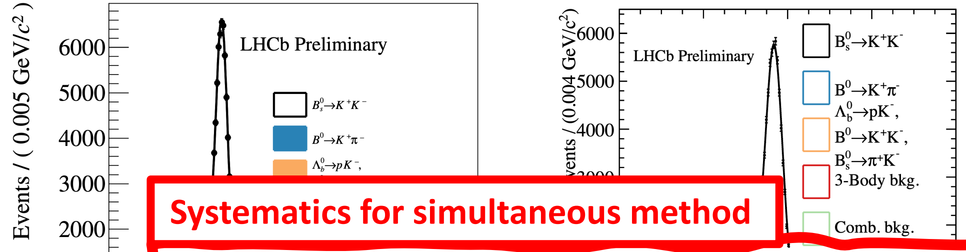
Compatibility measured with pseudoexperiment

Largest difference for $A^{KK}_{\Delta\Gamma}$ but large uncorrelated systematic uncertainties

Global compatibility is at 1.5σ dominated by difference in $A^{KK}_{\Delta\Gamma}$

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

Simultaneous method | **Per-event method**



LHCb Preliminary

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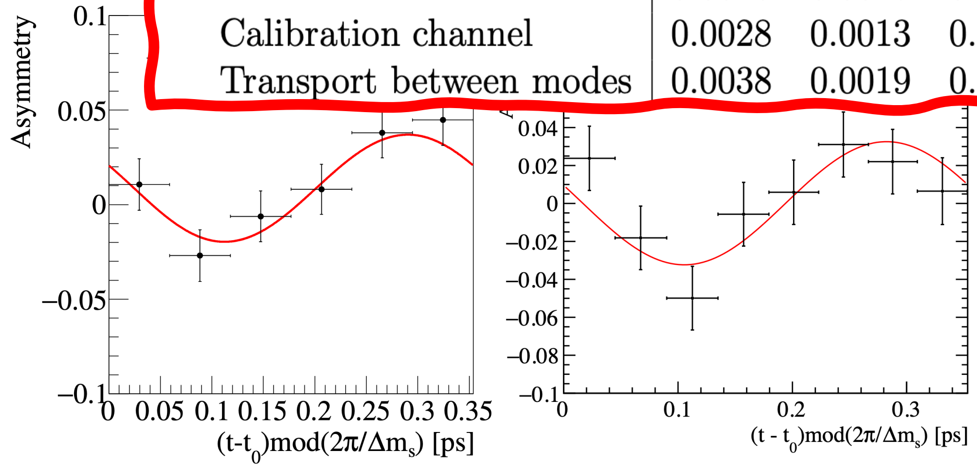
Systematics for simultaneous method

Source	$C_{\pi\pi}$	$S_{\pi\pi}$	$A_{CP}^{B^0}$	$A_{CP}^{B^0_s}$	C_{KK}	S_{KK}	$\mathcal{A}^{\Delta\Gamma}_{KK}$
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



Completely uncorrelated between methods

Compatibility measured with pseudoexperiment

Largest difference for $A^{KK}_{\Delta\Gamma}$ but large uncorrelated systematic uncertainties

Global compatibility is at 1.5σ dominated by difference in $A^{KK}_{\Delta\Gamma}$

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

From simultaneous method

LHCb Preliminary

$$
\begin{aligned}
C_{\pi\pi} &= -0.311 \pm 0.045 \pm 0.015,\\
S_{\pi\pi} &= -0.706 \pm 0.042 \pm 0.013,\\
A_{CP}^{B^0} &= -0.0824 \pm 0.0033 \pm 0.0033,\\
A_{CP}^{B_s^0} &= 0.236 \pm 0.013 \pm 0.011,\\
C_{KK} &= 0.164 \pm 0.034 \pm 0.014,\\
S_{KK} &= 0.123 \pm 0.034 \pm 0.015,\\
\mathcal{A}_{KK}^{\Delta\Gamma} &= -0.833 \pm 0.054 \pm 0.094,
\end{aligned}
$$

LHCb-PAPER-2020-029

Combination with Run1

LHCb-PAPER-2020-029

LHCb Preliminary

$$
\begin{aligned}
C_{\pi\pi} &= -0.320 \pm 0.038\\
S_{\pi\pi} &= -0.672 \pm 0.034\\
A_{CP}^{B^0} &= -0.0831 \pm 0.0034\\
A_{CP}^{B_s^0} &= 0.225 \pm 0.012\\
C_{KK} &= 0.172 \pm 0.031\\
S_{KK} &= 0.139 \pm 0.032\\
\mathcal{A}_{KK}^{\Delta\Gamma} &= -0.897 \pm 0.087
\end{aligned}
$$

Test for the SM [PLB621(2005)126]

LHCb Preliminary

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

Should be 0 in SM → No evidence of BSM effects

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

From simultaneous method

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LHCb-PAPER-2020-029

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\end{aligned}
$$

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

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

$$(C_{KK}, S_{KK}) \neq (0,0) \text{ @ } 6.7\sigma$$

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

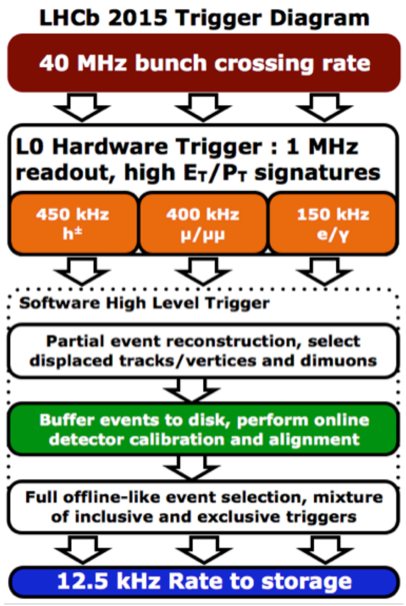
Conclusions

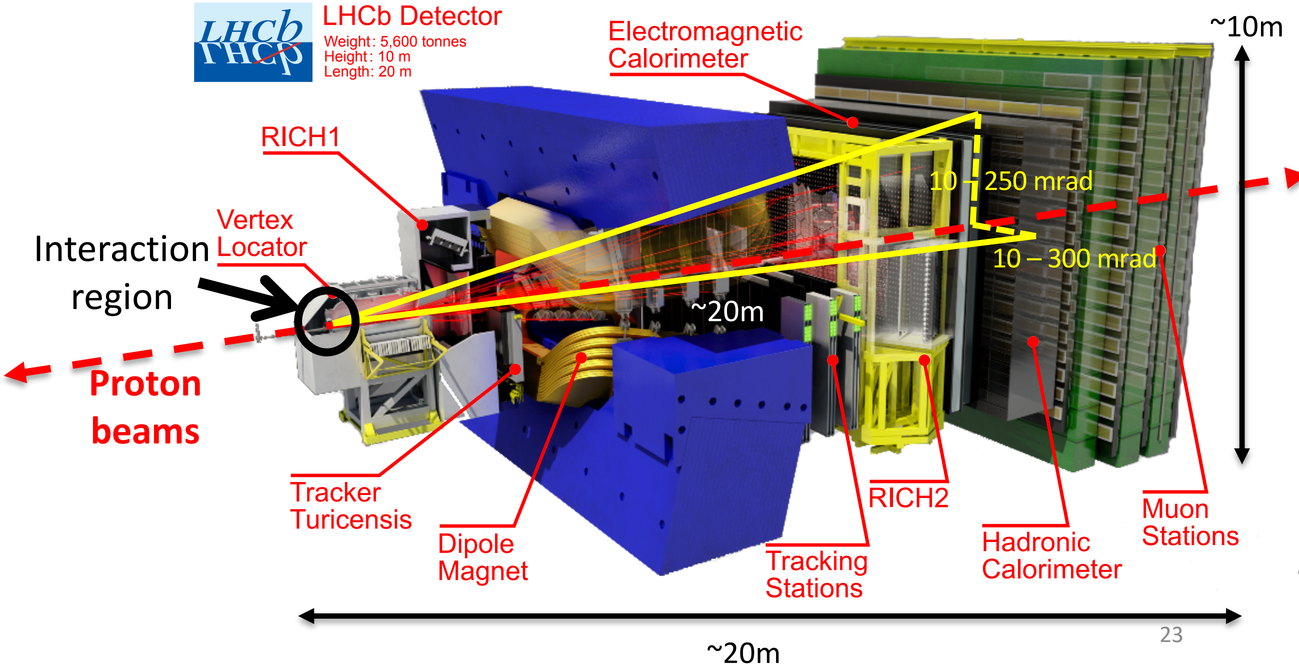
- Most recent time-dependent CP-violation measurement from LHCb have been presented
- Measurement of CKM angle γ from time-dependent amplitude analysis of $B_s^0 \to D_s^- K^+\pi^+\pi^-$ decays
  NEW
  - Exploit full LHCb data sample
  - In agreement with World Average
- Measurement of time-dependent and time-integrated CP asymmetries in $B_{(s)}^0 \to h^+h'^-$
  NEW
  - No evidence of BSM effect in the direct CP asymmetries of $B^0 \to K^+\pi^-$ and $B_s^0 \to K^-\pi^+$
  - First observation of time-dependent CP violation in B_s^0 decays with 6.7σ significance
  - Analysis based on a sub-sample of LHCb data → with full dataset a factor of about x2 in statistics is expected
- More time-dependent CP measurement in the pipeline with the full LHCb dataset
  - B_s^0 mixing phase from $B_s^0 \to J/\psi K^+K^-$, $B_s^0 \to J/\psi\pi^+\pi^-$ ($J/\psi \to e^+e^-, \mu^+\mu^-$)
  - $\sin 2\beta$ from $B_s^0 \to J/\psi K_S^0$
  - CKM angel γ from $B_s^0 \to D_s^- K^+$
  - B_s^0 mixing phase from $B_s^0 \to \phi\phi$ and $B_s^0 \to (K^+\pi^-)(K^-\pi^+)$
  - Many other…

Backup

The LHCb detector

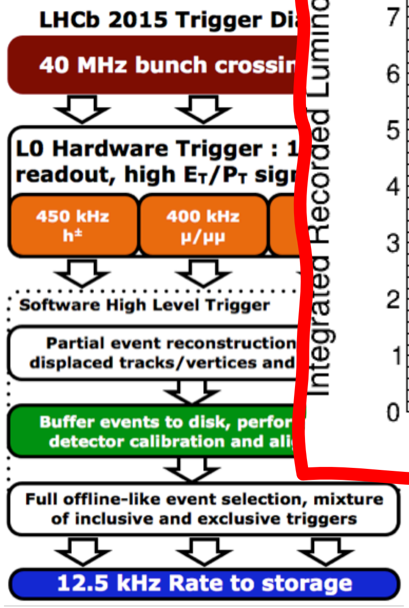
- LHCb is a forward spectrometer
  - Great time resolution (σ_t ~ 45 fs), momentum resolution ($\delta p/p$ ~ 0.4-0.6%), PID performances (RICH)
  - Real time calibration of detector

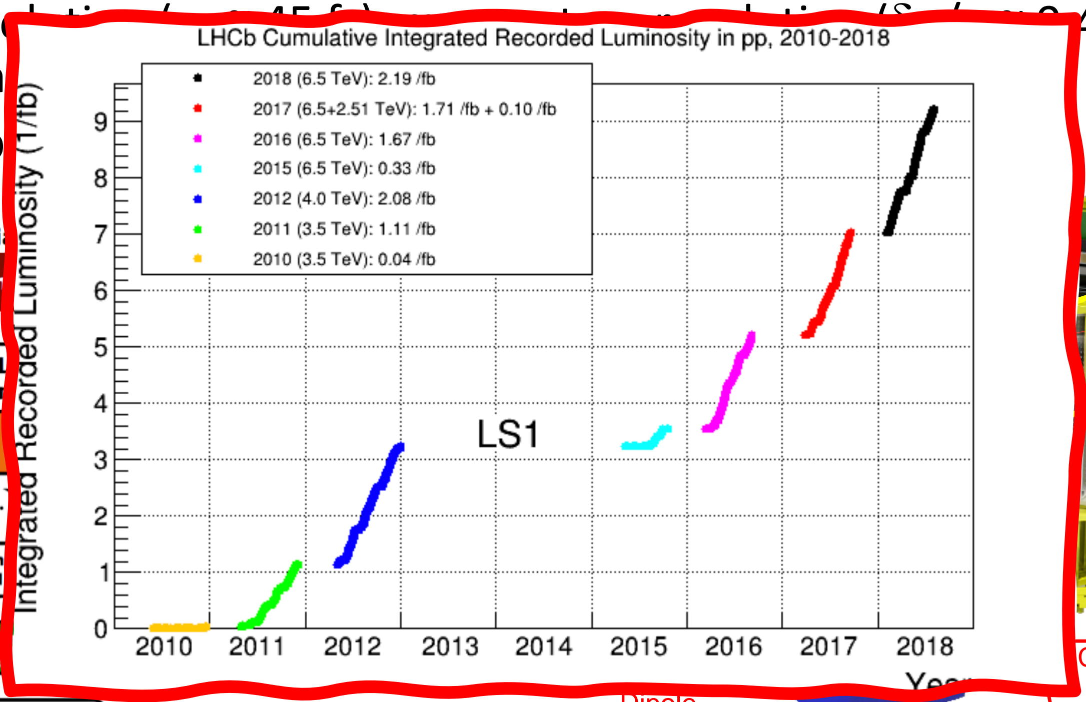


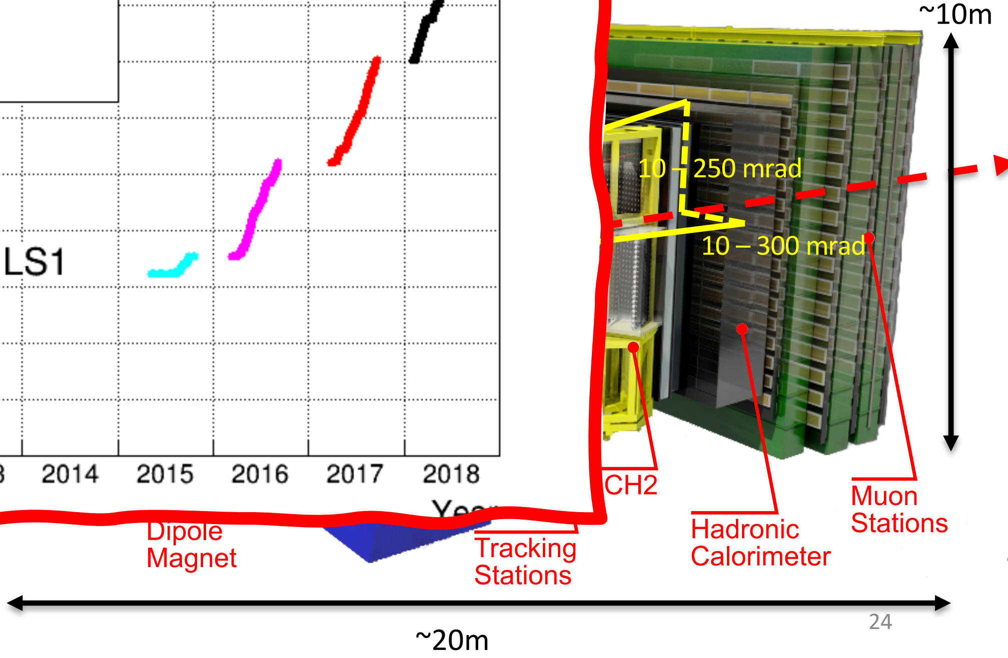


The LHCb detector

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

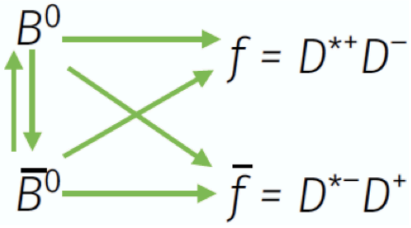






CP violation in $B^0 \to D^{*\pm}D^{\mp}$ [JHEP 03 (2020) 147]

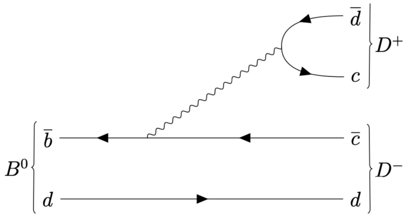
- Not a pure CP-eigenstate
  - Four decay rates

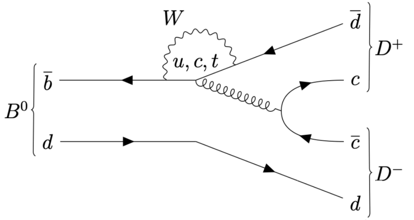


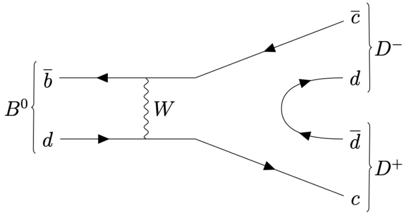
d = ±1 → B-flavour tag
r = ±1 → Final state tag

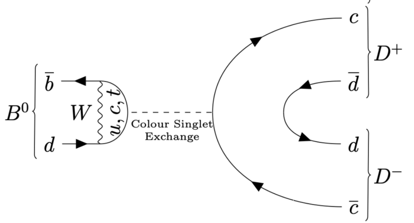
$$\frac{\mathrm{d}\Gamma(t)}{\mathrm{d}t} = \frac{e^{-t/\tau_d}}{8\tau_d}(1 + r\mathcal{A}_{D^*D}) \times \left[1 - d(S_{D^*D} + r\Delta S_{D^*D})\sin(\Delta m t) + d(C_{D^*D} + r\Delta C_{D^*D})\cos(\Delta m t)\right]$$

- Receive contributions from tree and penguin diagrams
  - Sensitive to physics beyond SM
  - Sensitive to B^0 mixing phase
  - If penguin contribution is small and no BSM physics is present → $S_{D^*D} = -\sin 2\beta$



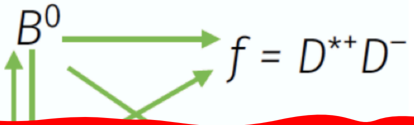






CP violation in $B^0 \to D^{*\pm} D^{\mp}$ [JHEP 03 (2020) 147]

- Not a pure CP-eigenstate
  - Four decay rates



d = ±1 → B-flavour tag

g

$$\frac{\mathrm{d}\Gamma(t)}{\mathrm{d}t} = \frac{e}{}$$

$$S_{D^*D} = \frac{1}{2}(S_f + S_{\bar f}),$$

$$\Delta S_{D^*D} = \frac{1}{2}(S_f - S_{\bar f}),$$

$$C_{D^*D} = \frac{1}{2}(C_f + C_{\bar f}),$$

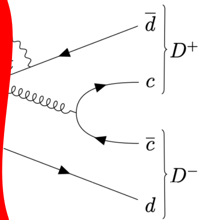
$$\Delta C_{D^*D} = \frac{1}{2}(C_f - C_{\bar f}),$$

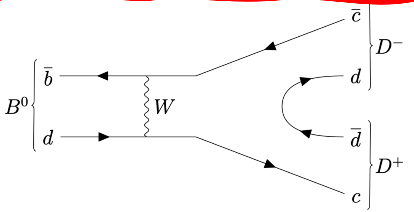
$$\mathcal{A}_{D^*D} = \mathcal{A}_{f\bar f}.$$

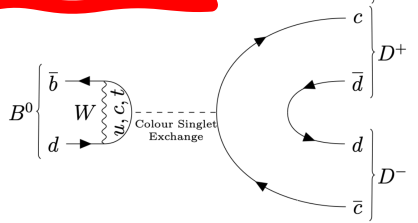
$$S_f = \frac{2\mathcal{I}m\lambda_f}{1+|\lambda_f|^2}, \qquad C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}, \qquad \lambda_f = \frac{q}{p}\frac{\bar A_f}{A_f}$$

$$\mathcal{A}_{f\bar f} = \frac{\left(|A_f|^2 + |\bar A_f|^2\right) - \left(|A_{\bar f}|^2 + |\bar A_{\bar f}|^2\right)}{\left(|A_f|^2 + |\bar A_f|^2\right) + \left(|A_{\bar f}|^2 + |\bar A_{\bar f}|^2\right)},$$

- Receive cor
  penguin dia
  - Sensitive
  - Sensitive to ... phase
  - If penguin contribution is small and no BSM physics is present → $S_{D^*D} = -\sin 2\beta$

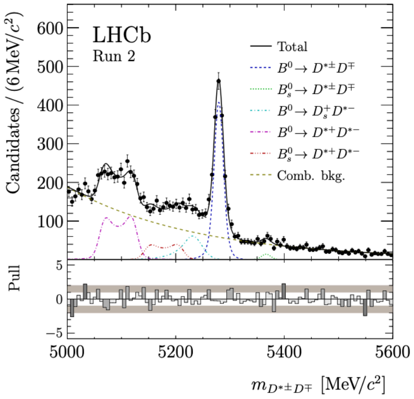


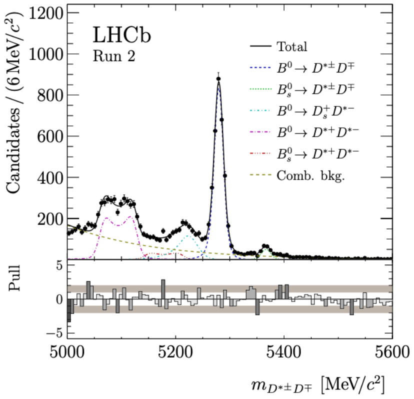




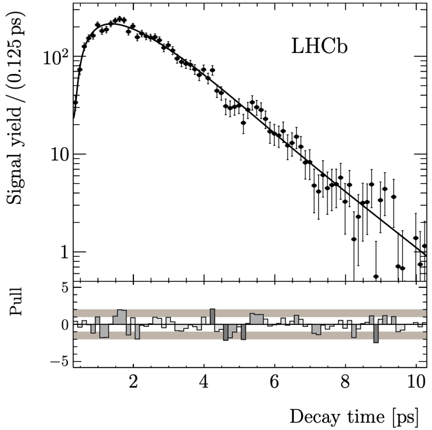
CP violation in $B^0 \to D^{*\pm}D^{\mp}$

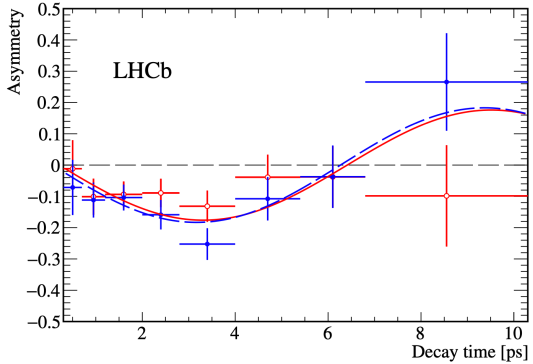
About 6k signal candidates in total





- Use full Run1+Run2 sample → ~9 fb^{-1}
- Final state reconstructed as $B^0 \to D^{*+}(D^0\pi^+)D^-$ with $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^-\pi^+$, $D^- \to K^-\pi^+\pi^-$
  - Simultaneous analysis of four subsamples: final state x Run1/2
- Correction for detection asymmetry between $D^{*+}D^-$/ $D^{*-}D^+$ using prompt $D^- \to K^-\pi^+\pi^-$ decays kinematically weighted to match signal distributions





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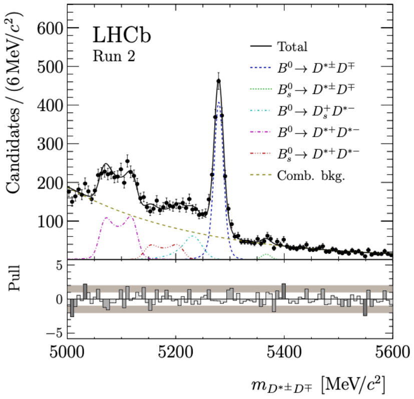
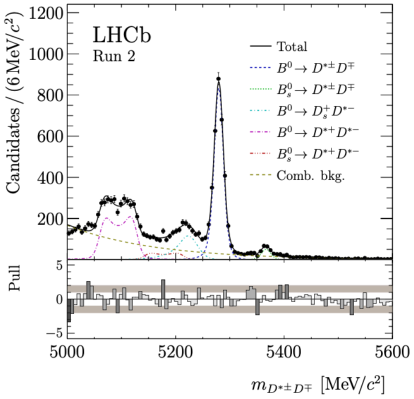
CP violation in $B^0 \to D^{*\pm}D^{\mp}$

About 6k signal candidates in total





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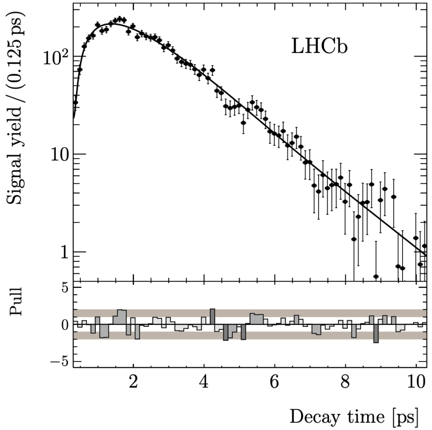
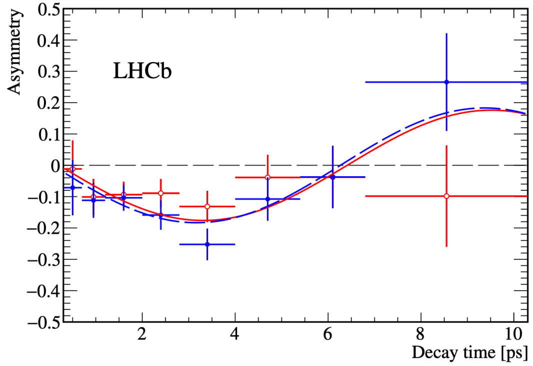
$$
\begin{aligned}
S_{D^*D} &= -0.861 \pm 0.077\,(\text{stat}) \pm 0.019\,(\text{syst})\,,\\
\Delta S_{D^*D} &= 0.019 \pm 0.075\,(\text{stat}) \pm 0.012\,(\text{syst})\,,\\
C_{D^*D} &= -0.059 \pm 0.092\,(\text{stat}) \pm 0.020\,(\text{syst})\,,\\
\Delta C_{D^*D} &= -0.031 \pm 0.092\,(\text{stat}) \pm 0.016\,(\text{syst})\,,\\
\mathcal{A}_{D^*D} &= 0.008 \pm 0.014\,(\text{stat}) \pm 0.006\,(\text{syst})\,.
\end{aligned}
$$





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- Compatible with determination from BaBar and Belle [PRD79(2009)032002, PRD85(2012)091106]
- No evidence of CPV in the decay
  - $C_{D^*D} \approx 0$ and $A_{D^*D} \approx 0$
  - Small contribution from penguins
- Fixing $C_{D^*D} = 0$ and $A_{D^*D} = 0$
  - $S_{D^*D} = -\sin 2\beta = -0.839 \pm 0.070$ → 1.9σ from SM

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

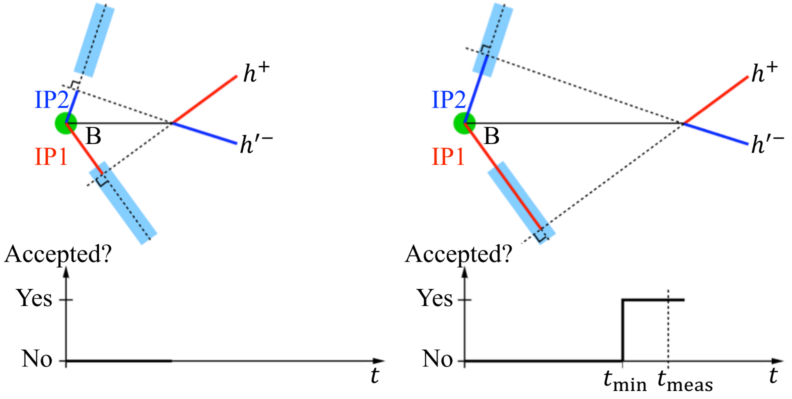
Systematic uncertainties for simultaneous method

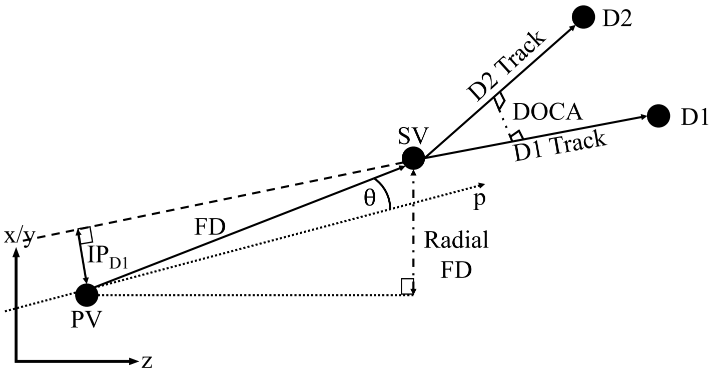
LHCb-PAPER-2020-029

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)





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

Run1 result

PRD98(2018)032004

$$C_{\pi^+\pi^-} = -0.34 \pm 0.06 \pm 0.01,$$
$$S_{\pi^+\pi^-} = -0.63 \pm 0.05 \pm 0.01,$$
$$C_{K^+K^-} = 0.20 \pm 0.06 \pm 0.02,$$
$$S_{K^+K^-} = 0.18 \pm 0.06 \pm 0.02,$$
$$A^{\Delta\Gamma}_{K^+K^-} = -0.79 \pm 0.07 \pm 0.10,$$
$$A^{B^0}_{CP} = -0.084 \pm 0.004 \pm 0.003,$$
$$A^{B^0_s}_{CP} = 0.213 \pm 0.015 \pm 0.007,$$

Updated input parameters

Run1 result

LHCb-PAPER-2020-029

$$C_{\pi^+\pi^-} = -0.34 \pm 0.06 \pm 0.01,$$
$$S_{\pi^+\pi^-} = -0.63 \pm 0.05 \pm 0.01,$$
$$C_{K^+K^-} = 0.19 \pm 0.06 \pm 0.02,$$
$$S_{K^+K^-} = 0.18 \pm 0.06 \pm 0.02,$$
$$A^{\Delta\Gamma}_{K^+K^-} = -0.97 \pm 0.07 \pm 0.10,$$
$$A^{B^0}_{CP} = -0.084 \pm 0.004 \pm 0.003,$$
$$A^{B^0_s}_{CP} = 0.213 \pm 0.015 \pm 0.007,$$

Input parameters

Parameter	Value
Δm_d	0.5065 ± 0.0019 ps^{-1}
Γ_d	0.6579 ± 0.0017 ps^{-1}
$\Delta\Gamma_d$	0
Δm_s	17.757 ± 0.021 ps^{-1}
Γ_s	0.6654 ± 0.0022 ps^{-1}
$\Delta\Gamma_s$	0.083 ± 0.007 ps^{-1}
$\rho(\Gamma_s, \Delta\Gamma_s)$	-0.292

Old WA

Run1 result

Parameter	Value
Δm_d	$0.5065 \pm 0.0019\,\mathrm{ps}^{-1}$
Γ_d	$0.6579 \pm 0.0017\,\mathrm{ps}^{-1}$
$\Delta\Gamma_d$	$0\,\mathrm{ps}^{-1}$
Δm_s	$17.757 \pm 0.021\,\mathrm{ps}^{-1}$
Γ_s	$0.6562 \pm 0.0021\,\mathrm{ps}^{-1}$
$\Delta\Gamma_s$	$0.082 \pm 0.005\,\mathrm{ps}^{-1}$
$\rho(\Gamma_s, \Delta\Gamma_s)$	-0.170

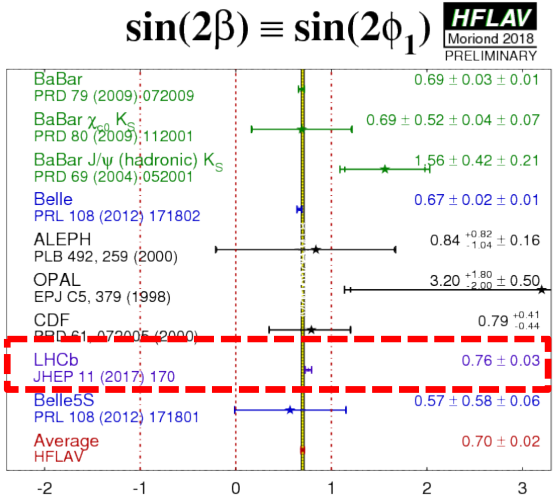
LHCb

EPJC79(2019)706

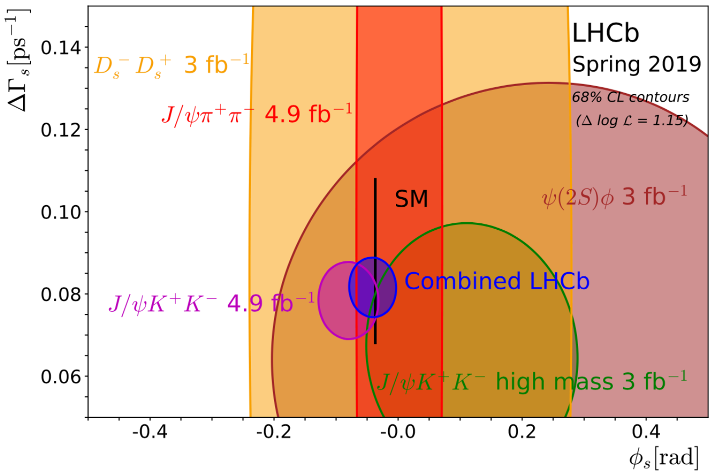
Golden modes from LHCb

- Time-dependent CPV is the golden way to access B^0 and B_s^0 mixing phases
  - Golden modes are $B_s^0 \to J/\psi h^+ h'^-$ and $\mathrm{B}^0 \to J/\psi K_S^0$
  - Current LHCb measurements based on partial sample of LHCb dataset → potential to relevant reduction in uncertainties
  - LHCb is working hard on legacy analyses of these mod

About x3 in luminosity still to be analysed



EPJC79(2019)706



Total LHCb dataset is more than twice the effective luminosity