Mixing and CPV in beauty and charm at LHCb

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Moriond QCD
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Outline

CKM angle γ

- LHCb combination γ and charm mixing parameters [JHEP 12(2021)141]
- CKM angle γ from $B^{\pm} \to Dh^{\pm}$ decays [arXiv:2112.10617] **NEW RESULT!**

CPV and mixing in charm

- Mass difference in $D^0 \to K^0_S\pi^+\pi^-$ [PRL127(2021)111801]
- Measurement of the charm mixing parameter y_{CP}-$y^{K\pi}_{CP}$ using two-body D^0 meson decays [arXiv:2202.09106] **NEW RESULT!**
- Measurement of *CP* asymmetries in $D^+_{(s)} \to \eta\pi^+$ and $D^+_{(s)} \to \eta^{'}\pi^+$ decays [LHCb-PAPER-2021-051 in preparation] **NEW RESULT!**

CPV in beauty

- Observation of large *CP* asymmetries in $B^{\pm} \to h^{\pm}h^+h^-$ [LHCb-PAPER-2021-049 and LHCb-PAPER-2021-050 in preparation] **NEW RESULT!**
- Search for *CP* violation in $B^0 \to p\bar{p}K^+\pi^-$ decays [LHCb-PAPER-2022-003 in preparation] **NEW RESULT!**

The CKM angle γ

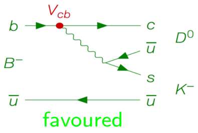
$$\gamma \equiv arg(-V_{ud}V_{ub}^*/V_{cd}V_{cb}^*)$$

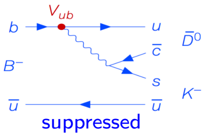
$$V_{CKM} \sim \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{-i\beta_s} & |V_{tb}| \end{pmatrix}$$

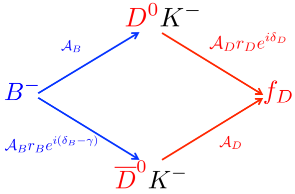
- Can be measured purely with tree level decays (SM benchmark)
- Theoretically very clean

Measuring γ

- Measured in the interference involving V_{cb} and V_{ub} to the same final state
- Golden channel: $B^{\pm} \to DK^{\pm}$







◇ Magnitude of amplitude(s): $\mathcal{A}_B$, $\mathcal{A}_D$
◇ Suppression factor(s): r_B, r_D
◇ Strong phase difference(s): δ_B, δ_D

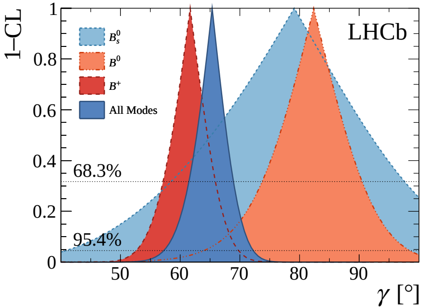
- B decay parameters are independent of the D^0 final state
- Combination of γ measurement from many decay modes gives best precision

Simultaneous determination of CKM angle γ [JHEP12(2021)141]

LHCb combination

$$\gamma = (65.4^{+3.8}_{-4.2})^\circ$$

- Combination includes measurements from B-meson and D-meson for the first time
- Excellent agreement with indirect results:
  - γ(UTFit)$= (65.8 \pm 2.2)^\circ$
  - γ(CKM fitter)$= (65.55^{+0.90}_{-2.65})^\circ$
- Most precise determination of γ from a single experiment to date



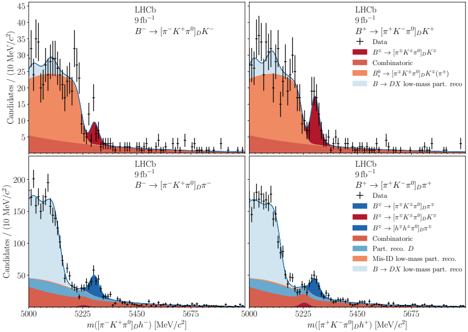
- Around two sigma tension between B^+ and B^0 results

Constraint on the CKM angle γ from $B^{\pm} \to Dh^{\pm}$ decays

Submitted to JHEP [arXiv:2112.10617] **NEW RESULT**

- 9 fb^{-1} from full LHCb dataset (2011-2018)
- Study of 8 final states
  - $B^{\pm} \to [K^{\pm}\pi^{\mp}\pi^{0}]_D h^{\pm}$ (quasi-ADS) fav.
  - $B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{0}]_D h^{\pm}$(quasi-ADS) sup.
  - $B^{\pm} \to [K^{\pm}K^{\mp}\pi^{0}]_D h^{\pm}$ (quasi-GLW)
  - $B^{\pm} \to [\pi^{\pm}\pi^{\mp}\pi^{0}]_D h^{\pm}$(quasi-GLW) ($h = K, \pi$)
- Fit to the B mass: simultaneous fit to 16 datasets
- 11 observables reported : ratio and asymmetries of yields $\to$ used to determine γ, r_B and δ_B

Yields($B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{0}]_D K^{\pm}$): 155 ± 19



Yields($B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{0}]_D \pi^{\pm}$):$293 \pm 27$

First observation of $B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^{0}]_D K^{\pm}$ with 7.8σ significance

Results Submitted to JHEP [arXiv:2112.10617] **NEW RESULT**

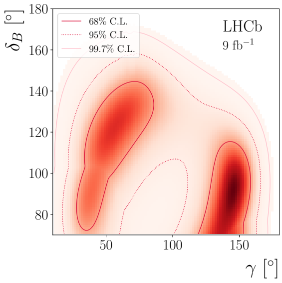
- World-best precision for the 11 observables measured
- Global minimum found at $\gamma = (145^{+9}_{-39})^\circ$
- Second solution close to the combined LHCb γ measurement

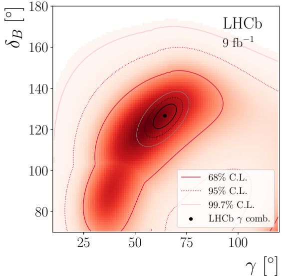
Results

$$\gamma = (56^{+24}_{-19})^\circ$$

$$\delta_B = (122^{+19}_{-23})^\circ$$

$$r_B = (9.3^{+1.0}_{-0.9}) \times 10^{-2}$$





Charm mixing and CPV in a nutshell

- **Neutral meson mixing**

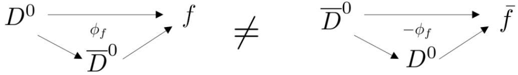
$$|D_{1,2}\rangle = p\big|D^0\big\rangle + q\big|\bar{D}^0\big\rangle$$

- **Mixing parameters**

$$x = 2(m_1 - m_2)/\Gamma_1 + \Gamma_2 \qquad\qquad y = \Gamma_1 - \Gamma_2/\Gamma_1 + \Gamma_2$$

$\rightarrow$ expected to be small ($\mathcal{O}(10^{-3})$)

- ***CP* violation**
  - Direct *CP* violation: $\Gamma(D^0 \rightarrow f) \neq \bar{\Gamma}(\bar{D}^0 \rightarrow f)$
  - *CP* violation in mixing: $|q/p| \neq 1$
  - *CP* violation in interference of mixing and decay: $\phi_f = \arg(q\bar{A}_f/pA_f) \neq 0$

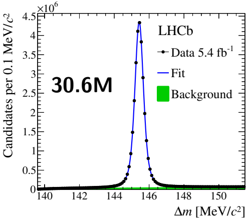


Observation of the mass difference in $D^0 \to K^0_S \pi^+ \pi^-$

[PRL127(2021) 111801]

Measurement of mixing and *CP* violation parameters

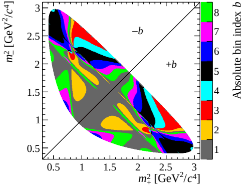
- $D^{*+} \to D^0(\to K^0_S \pi^+ \pi^-)\pi^+$



5.4 fb^{-1} from Run 2 (2016-2018)

"bin-flip" method

- Model-independent approach avoiding the need for modelling efficiency variation
- Measure ratios of events in Dalitz plot bins of constant strong phase difference



Results mixing parameters

$\mathbf{x = (3.98^{+0.56}_{-0.54}) \times 10^{-3}}$ $\quad y = (4.6^{+1.5}_{-1.4}) \times 10^{-3}$

$|q/p| = 0.996 \pm 0.052 \quad \phi = 0.056^{+0.047}_{-0.051}$

First observation of a difference between D^0 mass eigenstates (7σ significance)

Measurement of y_{CP}-$y_{CP}^{K\pi}$ using two-body D^0 meson decays

Submitted to PRD [arXiv:2202.09106] **NEW RESULT**

- Dataset: 6 fb^{-1} from Run 2 (2015-18)
- D^0 mixing studied using $D^0 \to K^-\pi^+$ and $D^0 \to f(f = K^+K,\pi^+\pi^-)$
- $y_{CP} - y_{CP}^{K\pi} \approx y(1+\sqrt{R_D})$, with $R_D = \frac{\mathcal{B}(D^0\to K^-\pi^+)}{\mathcal{B}(D^0\to K^+\pi^-)}$
- Allows to constrain mixing parameter $y = \frac{\Gamma_1-\Gamma_2}{\Gamma_1+\Gamma_2}$
- D^0 meson obtained from $D^{*+} \to D^0(\to f)\pi^{\pm}$

Experimental observable

$$y_{CP} - y_{CP}^{K\pi} \equiv \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to K^-K^+(\pi^-\pi^+))} - 1$$

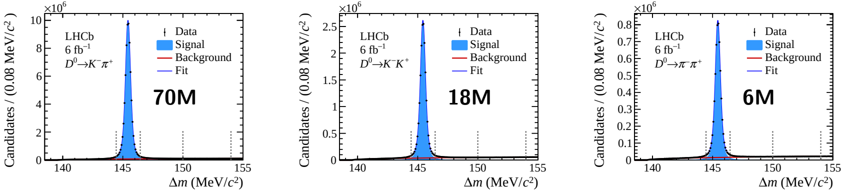
Measurement of y_{CP}-$y_{CP}^{K\pi}$ using two-body D^0 meson decays

Submitted to PRD [arXiv:2202.09106] **NEW RESULT**

- $y_{CP}^{f} - y_{CP}^{K\pi}$ obtained with an exponential fit to R^f

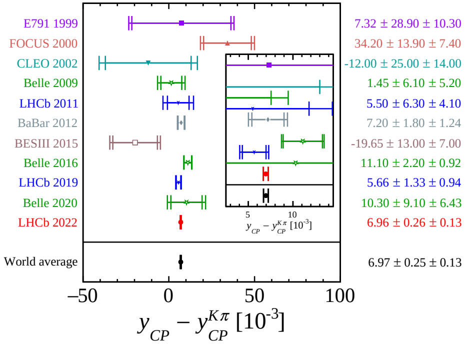
$$R^f(t) = \frac{N(D^0 \to f, t)}{N(D^0 \to K^-\pi^+, t)} \propto e^{-(y_{CP}^{f} - y_{CP}^{K\pi})t/\tau_{D^0}} \times \frac{\varepsilon(f,t)}{\varepsilon(K^-\pi^+,t)}$$

- $y_{CP} - y_{CP}^{K\pi}$: average of $y_{CP}^{KK} - y_{CP}^{K\pi}$ and $y_{CP}^{\pi\pi} - y_{CP}^{K\pi}$
- Efficiencies equalised by matching and weighting the kinematics $\to$ cancel in the ratio
- Subtract the combinatorial bkg by fitting $\Delta m = m(h^- h^+ \pi^+_{tag}) - m(h^- h^+)$
- Validation of the analysis procedure with three distinct methods

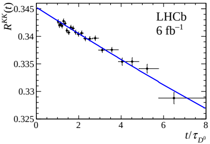


Results Submitted to PRD [arXiv:2202.09106] **NEW RESULT**

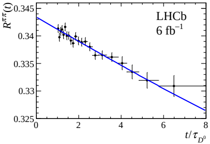
Result combining $y_{CP}^{KK} - y_{CP}^{K\pi}$ and $y_{CP}^{\pi\pi} - y_{CP}^{K\pi}$



$y_{CP}^{KK} - y_{CP}^{K\pi} = (7.08 \pm 0.30 \pm 0.14) \times 10^{-3}$



$y_{CP}^{\pi\pi} - y_{CP}^{K\pi} = (6.57 \pm 0.53 \pm 0.16) \times 10^{-3}$



LHCb 2022: $y_{CP} - y_{CP}^{K\pi} = (6.96 \pm 0.26_{stat} \pm 0.13_{sys}) \times 10^{-3}$

$4\times$ more precise than current world average

$(y_{CP} - y_{CP}^{K\pi} = (7.16 \pm 0.93_{stat} \pm 0.60_{sys}) \times 10^{-3})$

Measurement of CP asymmetries in $D^+_{(s)} \to \eta^{(\prime)}\pi^+$ decays

[LHCb-PAPER-2021-051 in preparation] **NEW RESULT**

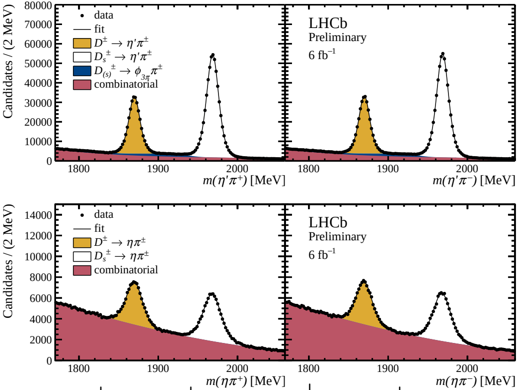
Dataset: 6 fb^{-1} from Run 2 (2015-18)

Measurement of $\mathcal{A}_{CP}$ in $D^+_{(s)} \to \eta^{(\prime)}\pi^+$ decays with $\eta^{(\prime)} \to \gamma\pi^+\pi^-$

$$\mathcal{A}^{CP}(D^+_{(s)} \to f^+) = \mathcal{A}^{raw}(D^+_{(s)} \to f^+) - \mathcal{A}^{prod}(D^+_{(s)}) - \mathcal{A}^{det}(f^+)$$

- $\mathcal{A}^{prod}$ and $\mathcal{A}^{det}$ subtracted with $D^+_{(s)} \to \phi(K^+K^-)\pi^+$
- $\mathcal{A}^{raw}$: fit to $m(\pi^+\pi^-\pi^+\gamma)$ in bins of $m(\eta^{(\prime)})$
  - m(η):[526, 570] MeV/c^2
  - m($\eta^\prime$):[936, 976] MeV/c^2

$D^\pm \to \eta^\prime\pi^\pm$: 555k, $D_s^\pm \to \eta^\prime\pi^\pm$: 1M

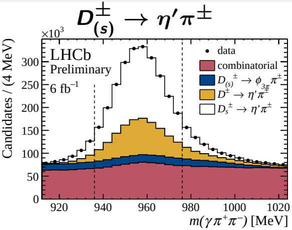


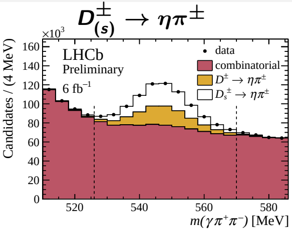
$D^\pm \to \eta\pi^\pm$: 110k, $D_s^\pm \to \eta\pi^\pm$: 135k

Measurement of CP asymmetries in $D^+_{(s)} \to \eta^{(\prime)}\pi^+$ decays

[LHCb-PAPER-2021-051 in preparation] **NEW RESULT**

Projection of the fit results on $m(\gamma\pi^+\pi^-)$





Measured A_{CP} asymmetries

- $\mathcal{A}^{CP}(D^+ \to \eta\pi^+) = (0.34 \pm 0.66_{stat} \pm 0.16_{syst} \pm 0.05_{D^+\to\phi\pi^+})\%$*
- $\mathcal{A}^{CP}(D^+_s \to \eta\pi^+) = (0.32 \pm 0.51_{stat} \pm 0.12_{syst})\%$
- $\mathcal{A}^{CP}(D^+ \to \eta'\pi^+) = (0.49 \pm 0.18_{stat} \pm 0.06_{syst} \pm 0.05_{D^+\to\phi\pi^+})\%$ *
- $\mathcal{A}^{CP}(D^+_s \to \eta'\pi^+) = (0.01 \pm 0.12_{stat} \pm 0.08_{syst})\%$*

*Most precise to date

All results compatible with *CP* conservation

Direct CP violation in $B^{\pm} \to h^{\pm}h^{+}h^{-}$ decays

[LHCb-PAPER-2021-049 in preparation] **NEW RESULT**

- Involve both **tree** $b \to u$ and **penguin** $b \to s, d$ transitions
- Phase-space rich in resonant structures

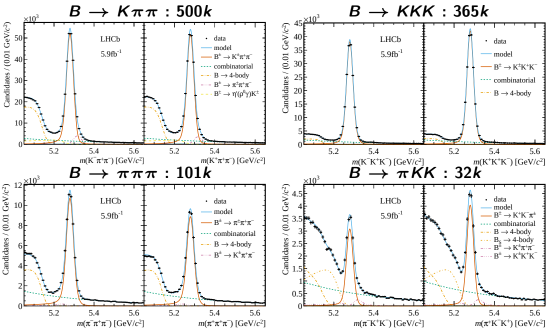
CP asymmetry measurements with 5.9 fb^{-1} from Run 2 (2015-18)

CP violation observable

$$A_{CP} = \frac{A^{acc}_{raw} - A^{prod}}{1 - A^{acc}_{raw} A^{prod}}$$

- Simultaneous invariant mass fit to B^{+}/B^{-}
- $A^{acc}_{raw} = \frac{(N_{B-}/R) - N_{B+}}{(N_{B-}/R) + N_{B+}}$

  with $R = \frac{<\varepsilon(B+, DP)>}{<\varepsilon(B-, DP)>}$
- A^{prod} obtained using $B^{\pm} \to J/\psi K^{\pm}$



Direct CP violation in $B^\pm \to h^\pm h^+ h^-$ decays

[LHCb-PAPER-2021-049 in preparation] **NEW RESULT**

Results for the phase-space integrated CP asymmetries

- $A_{CP}(B^\pm \to K^\pm \pi^+ \pi^-) = (+1.1 \pm 0.2_{stat} \pm 0.3_{syst} \pm 0.3_{J/\psi K^\pm})\%$ (2.4σ)
- $A_{CP}(B^\pm \to K^\pm K^+ K^-) = (-3.7 \pm 0.2_{stat} \pm 0.2_{syst} \pm 0.3_{J/\psi K^\pm})\%$ (8.5σ)
- $A_{CP}(B^\pm \to \pi^\pm \pi^+ \pi^-) = (+8.0 \pm 0.4_{stat} \pm 0.3_{syst} \pm 0.3_{J/\psi K^\pm})\%$ (14.1σ)
- $A_{CP}(B^\pm \to \pi^\pm K^+ K^-) = (-11.4 \pm 0.7_{stat} \pm 0.3_{syst} \pm 0.3_{J/\psi K^\pm})\%$ (13.6σ)

First observation of CPV in $B^\pm \to K^\pm K^+ K^-$ at 8.5σ and $B^\pm \to \pi^\pm \pi^+ \pi^-$ at 14.1σ

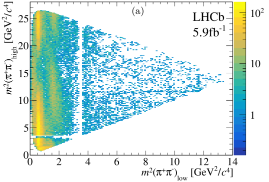
CPV in $B^\pm \to \pi^\pm K^+ K^-$ consistent and more precise than previous measurement [PRD90(2014)112004]

Local *CP* asymmetries in the phase space

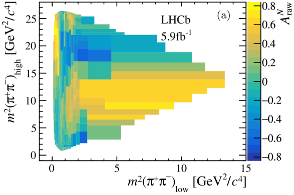
[LHCb-PAPER-2021-049 in preparation] **NEW RESULT**

Selected result: $B^\pm \to \pi^\pm\pi^+\pi^-$

Dalitz Plot distribution for $B^\pm \to \pi^\pm\pi^+\pi^-$



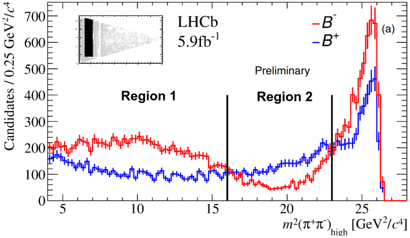
A_{CP} in bins of the Dalitz Plot for $B^\pm \to \pi^\pm\pi^+\pi^-$



- Model-independent for mapping local *CP* asymmetries [Phys.Rev.D80,096006]

Hadronic rescattering region $\pi\pi \leftrightarrow KK$

$1 < m^2(\pi^+\pi^-)_{low} < 2.25$ GeV$^2/c^4$



Region 1

$$A_{CP} = (+30.3 \pm 0.9_{stat} \pm 0.4_{syst} \pm 0.3_{J/\psi K^\pm})\%$$

Region 2

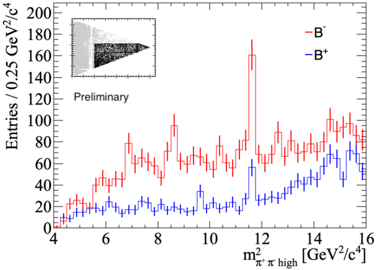
$$A_{CP} = (-28.4 \pm 1.7_{stat} \pm 0.7_{syst} \pm 0.3_{J/\psi K^\pm})\%$$

Local *CP* asymmetries in the phase space

[LHCb-PAPER-2021-049 in preparation] **NEW RESULT**

Selected result: $B^\pm \to \pi^\pm\pi^+\pi^-$

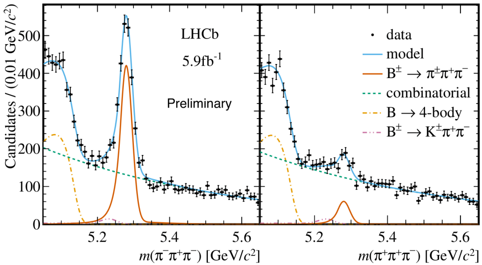
Region around $\chi_{c0}(1P)$ mass



First indication of the presence of $B^\pm \to \pi^\pm\chi_{c0}(\to \pi^+\pi^-)$

- Decay driven by $V_{bc}V^*_{cd}$
  $\to$ no *CP* violating phase

$B^\pm$ mass fit in $\chi_{c0}(1P)$ region



$$A_{CP} = (+74.5 \pm 2.7_{stat} \pm 1.8_{syst} \pm 0.3_{J/\psi K^\pm})\%$$

Largest *CP* violation ever observed

- *CPV* could arise from interference between χ_{c0} and non-resonant [PRL(1995)74984], χ_{c0} and double-charm rescattering[PLB806(2020)135490]

Search for direct CP violation in $B \to PV$ decays

[LHCb-PAPER-2021-050 in preparation] **NEW RESULT**

$B \to R(\to h_1^- h_2^+) h_3^+$

$s_\perp = m^2(h_1^- h_3^+)$
$s_\parallel = m^2(h_1^- h_2^+)$
$\theta \equiv$ helicity angle

- Model-independent experimental approach to measure CP asymmetries in $B \to PV$ decays [PRD94(2016)054028]
  $\to$ obviate the need of amplitude analysis

For low mass and narrow resonances $B^\pm$ decay amplitudes ($\mathcal{M}_\pm$):

$$|\mathcal{M}_\pm|^2 = f(\cos\theta(m_V^2, s_\perp)) = p_0^\pm + p_1^\pm \cos\theta(m_V^2, s_\perp) + p_2^\pm \cos^2\theta(m_V^2, s_\perp)$$

CP violation observable

$$A_{CP}^{B\to PV} = \frac{|\mathcal{M}_-|^2 - |\mathcal{M}_+|^2}{|\mathcal{M}_-|^2 + |\mathcal{M}_+|^2} = \frac{p_2^- + p_2^+}{p_2^- + p_2^+}$$

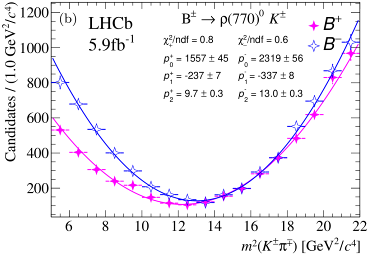
Selected result:

CPV in $B^\pm \to \rho(770)^0(\to \pi^+\pi^-)K^\pm$

$$\mathcal{A}_{CP}^{\rho(770)^0 K} = (+15.0 \pm 1.9_{stat} \pm 1.1_{syst})\%$$

First time observed (6.8σ)

Quadractic fit for $\rho(770)^0$ in $B^\pm \to K^\pm\pi^+\pi^-$



Search for CP violation using $\hat{T}$-odd correlations in $B^0 \to p\bar{p}K^+\pi^-$ decays [LHCb-PAPER-2022-003 in preparation] **NEW RESULT**

$\hat{T}$-odd Triple Product Asymmetries ($A_{\hat{T}}$)

Based on scalar triple products
$C_{\hat{T}} \equiv \vec{p}_{K^+} \cdot (\vec{p}_{\pi^-} \times \vec{p}_{\bar{p}})$

$$\boldsymbol{A_{\hat{T}} = \frac{N_{B^0}(C_{\hat{T}} > 0) - N_{B^0}(C_{\hat{T}} < 0)}{N_{B^0}(C_{\hat{T}} > 0) + N_{B^0}(C_{\hat{T}} < 0)}}$$

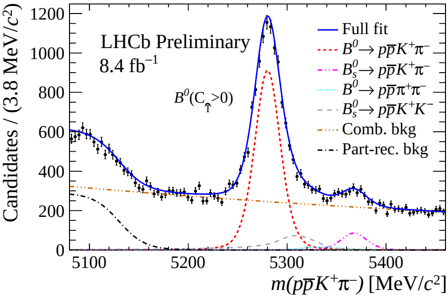
***CP* and *P* violating asymmetries observables**:

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

$$a_{P}^{\hat{T}-odd} = \frac{1}{2}(A_{\hat{T}} + \bar{A}_{\hat{T}})$$

- Insensitive to production and detector-induced asymmetries
- Measurements in bins and integrated over the phase space

- Simultaneous fit to four subsamples:
  $(B^0(C_{\hat{T}} > 0), B^0(C_{\hat{T}} < 0), \bar{B}^0(C_{\hat{T}} > 0), \bar{B}^0(C_{\hat{T}} < 0))$
- Dataset: 8.4 fb^{-1} from Run1+Run2



Search for CP violation using $\hat{T}$-odd correlations in $B^0 \to p\bar{p}K^+\pi^-$ decays [LHCb-PAPER-2022-003 in preparation] **NEW RESULT**

Results

Phase-space integrated asymmetries

$a_{CP}^{\hat{T}-odd} = (0.51 \pm 0.85_{stat} \pm 0.08_{syst})\%$

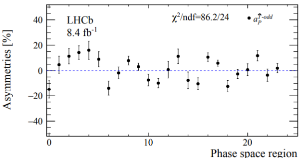
No evidence for *CPV*

$a_{P}^{\hat{T}-odd} = (1.49 \pm 0.85_{stat} \pm 0.08_{syst})\%$

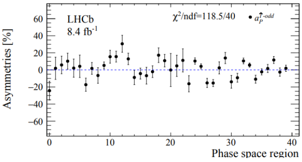
No evidence for *P* violation

Phase space bins measurements

$a_{P}^{\hat{T}-odd}$ (24 bins)



$a_{P}^{\hat{T}-odd}$ (40 bins)



- 2 binning schemes based on $m_{K^+\pi^-}$, $m_{p\bar{p}}$ and angular variables
- **No evidence for CPV in regions of the phase space**
- **Local P violation at 5.8σ**

Summary

- Tree-level γ measurements approaching precision of global fits
- Highest precision measurements on charm mixing parameters:
  - First observation of a nonzero mass difference in the D^0 system (Statistical uncertainty of 0.18 $\times 10^{-3}$)
  - Measurement of the charm oscillation parameter $y_{CP} - y_{CP}^{K\pi}$ (Statistical uncertainty of 0.26 $\times 10^{-3}$)
- First observation of phase-space integrated CPV in $B^\pm \to K^\pm K^+ K^-$ and $B^\pm \to \pi^\pm \pi^+ \pi^-$ decays
- Highest CP asymmetry ever measured in a localized region of the phase-space ($+75\%$ in $B^\pm \to \pi^\pm \pi^+ \pi^-$ decays)
- Many exciting beauty and charm results to be released this year with the Run 2 dataset

Thank you for your attention

backup

Simultaneous determination of CKM angle γ [JHEP12(2021)141]

LHCb measurements used in the combination

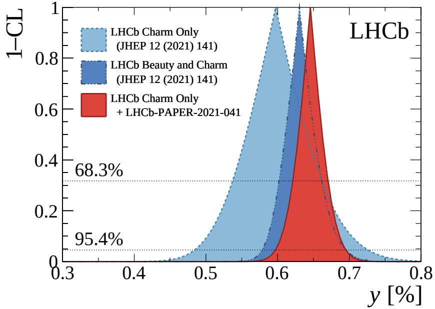
B decay	D decay	Ref.	Dataset	Status since Ref. [17]
$B^\pm \to Dh^\pm$	$D \to h^+h^-$	[20]	Run 1&2	**Updated**
$B^\pm \to Dh^\pm$	$D \to h^+\pi^-\pi^+\pi^-$	[21]	Run 1	As before
$B^\pm \to Dh^\pm$	$D \to h^+h^-\pi^0$	[22]	Run 1	As before
$B^\pm \to Dh^\pm$	$D \to K^0_S h^+h^-$	[19]	Run 1&2	**Updated**
$B^\pm \to Dh^\pm$	$D \to K^0_S K^\pm\pi^\mp$	[23]	Run 1&2	**Updated**
$B^\pm \to D^*h^\pm$	$D \to h^+h^-$	[20]	Run 1&2	**Updated**
$B^\pm \to DK^{*\pm}$	$D \to h^+h^-$	[24]	Run 1&2(*)	As before
$B^\pm \to DK^{*\pm}$	$D \to h^+\pi^-\pi^+\pi^-$	[24]	Run 1&2(*)	As before
$B^\pm \to Dh^\pm\pi^+\pi^-$	$D \to h^+h^-$	[25]	Run 1	As before
$B^0 \to DK^{*0}$	$D \to h^+h^-$	[26]	Run 1&2(*)	**Updated**
$B^0 \to DK^{*0}$	$D \to h^+\pi^-\pi^+\pi^-$	[26]	Run 1&2(*)	**New**
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	[27]	Run 1	As before
$B^0 \to D^\mp\pi^\pm$	$D^+ \to K^-\pi^+\pi^+$	[28]	Run 1	As before
$B^0_s \to D^\mp_s K^\pm$	$D^+_s \to h^+h^-\pi^+$	[29]	Run 1	As before
$B^0_s \to D^\mp_s K^\pm\pi^+\pi^-$	$D^+_s \to h^+h^-\pi^+$	[30]	Run 1&2	**New**
D decay	**Observable(s)**	**Ref.**	**Dataset**	**Status since Ref. [17]**
$D^0 \to h^+h^-$	ΔA_{CP}	[31,32,33]	Run 1&2	**New**
$D^0 \to h^+h^-$	y_{CP}	[34]	Run 1	**New**
$D^0 \to h^+h^-$	ΔY	[35,36,37,38]	Run 1&2	**New**
$D^0 \to K^+\pi^-$ (Single Tag)	$R^\pm$, $(x'^\pm)^2$, $y'^\pm$	[39]	Run 1	**New**
$D^0 \to K^+\pi^-$ (Double Tag)	$R^\pm$, $(x'^\pm)^2$, $y'^\pm$	[40]	Run 1&2(*)	**New**
$D^0 \to K^\pm\pi^\mp\pi^+\pi^-$	$(x^2+y^2)/4$	[41]	Run 1	**New**
$D^0 \to K^0_S\pi^+\pi^-$	x, y	[42]	Run 1	**New**
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[43]	Run 1	**New**
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[44]	Run 2	**New**

- Same strategy used in previous LHCb combination
- Frequentist treatment: 151 observables used to determine 52 parameters
- Combination includes new and updated measurements from B-meson and D-meson measurements for the first time
- Auxiliary input from other experiments used in the combination (hadronic parameters and coherence factors)

Measurement of y_{CP}-$y_{CP}^{K\pi}$ using two-body D^0 meson decays

Submitted to PRD [arXiv:2202.09106] **NEW RESULT**

New value of the charm mixing parameter **y** and $\delta_D^{K\pi}$ using LHCb CHARM combination



$$y = (6.46^{+0.24}_{-0.25}) \times 10^{-3}$$

$\times 2$ improvement

$$\delta_D^{K\pi} = (192.1^{+3.7}_{-4.0})$$

3σ deviation from 180°

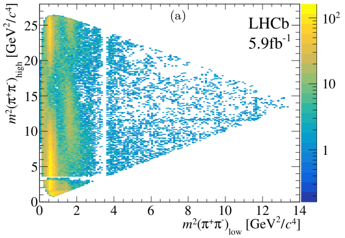
Evidence for U-spin symmetry breaking

Local *CP* asymmetries in the phase-space

[LHCb-PAPER-2021-049 in preparation] **NEW RESULT**

- Model-independent method for mapping local *CP* asymmetries [Phys.Rev.D80,096006]
- Adaptive binning algorithm → same number of signal yield per bin
- Acceptance correction implemented
- 10 regions defined to study localised *CP* asymmetries

Dalitz Plot distribution for $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$



Asymmetry Map: A_{CP} in bins of the Dalitz Plot for $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$