Supplementary material of LHCb-PAPER-2020-045

Table 1: Number of signal candidates after removing the $m(D^0\pi^+_{\rm tag})$ background, in millions.

Data sample	$\int \mathcal{L}\,\mathrm{d}t$ [fb^{-1}]	$D^0 \to K^-\pi^+$	$D^0 \to K^+K^-$	$D^0 \to \pi^+\pi^-$
2015 *MagUp*	0.3	9.9	1.1	0.4
2015 *MagDown*		15.5	1.7	0.6
2016 *MagUp*	1.6	70.8	7.7	2.6
2016 *MagDown*		77.0	8.5	2.8
2017 *MagUp*	1.7	80.1	8.9	2.8
2017 *MagDown*		83.2	9.4	2.9
2018 *MagUp*	2.1	94.9	10.7	3.4
2018 *MagDown*		87.6	9.9	3.1
Total	5.7	519.1	57.9	18.4

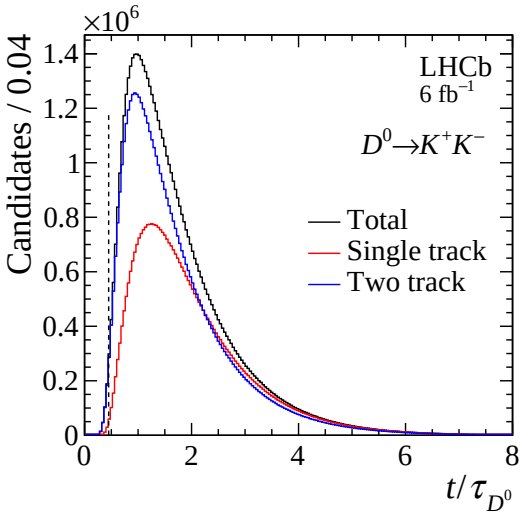

Figure 1: Distribution of the D^0 decay time, separately for different requirements at the first stage of the software trigger. The vertical dashed line represents the lower requirement on decay time ($0.45\,\tau_{D^0}$); the upper requirement is $8\,\tau_{D^0}$.

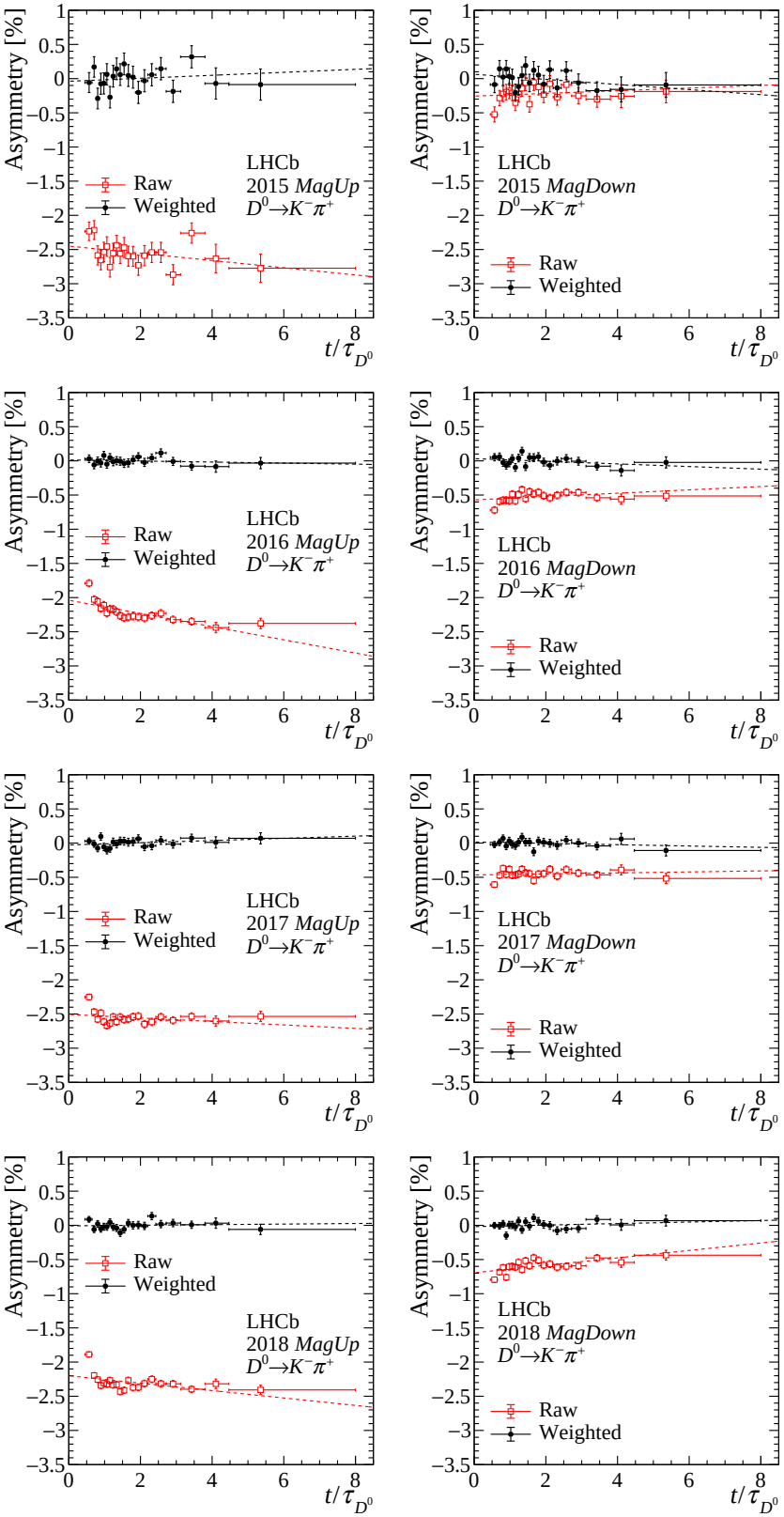

Figure 2: Linear fit to the time-dependent asymmetry of the $D^0 \to K^-\pi^+$ sample (red) before and (black) after the kinematic weighting. The contribution of secondary decays from B mesons to the asymmetry is not subtracted.

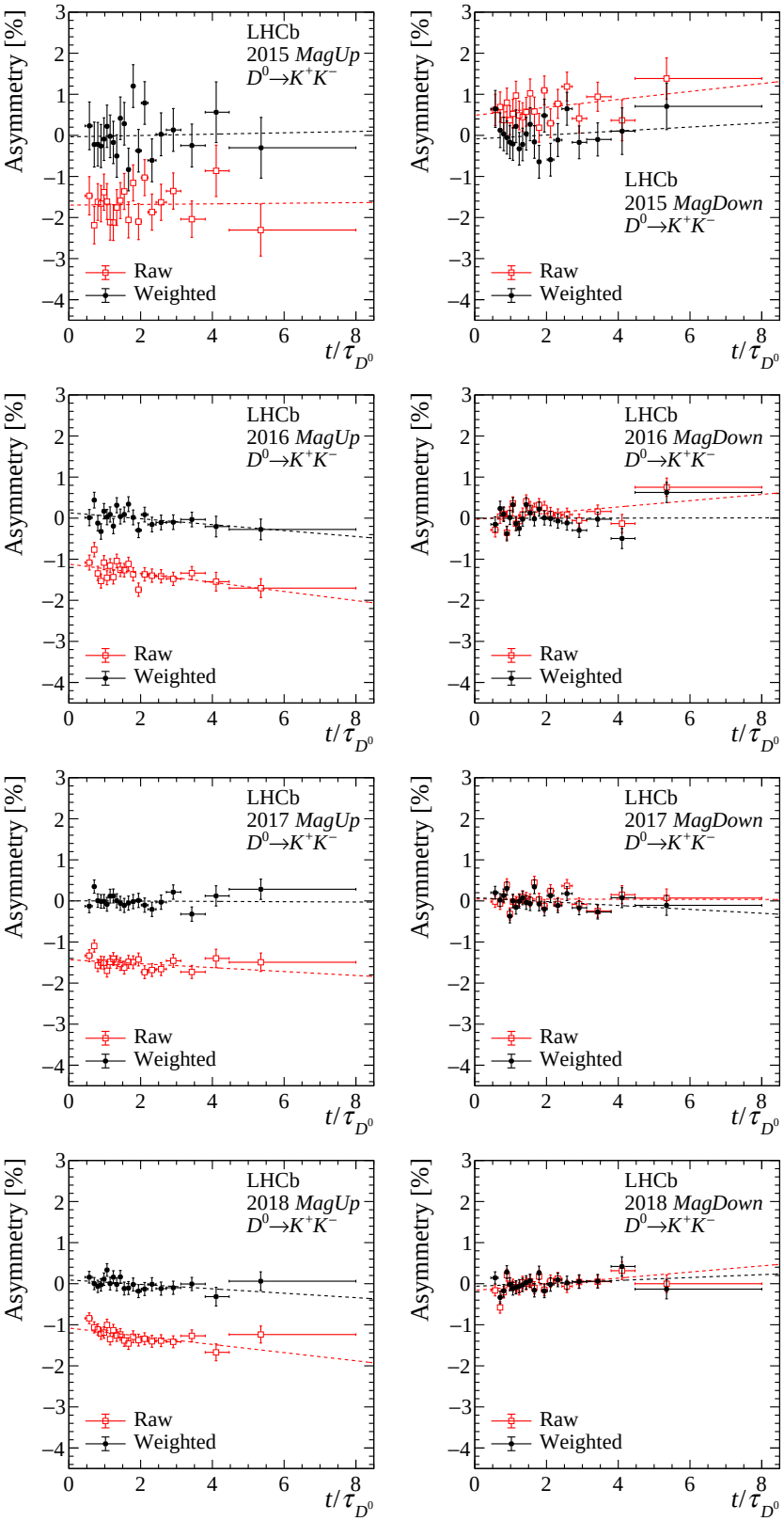

Figure 3: Linear fit to the time-dependent asymmetry of the $D^0 \to K^+K^-$ sample (red) before and (black) after the kinematic weighting. The contribution of secondary decays from B mesons to the asymmetry is not subtracted.

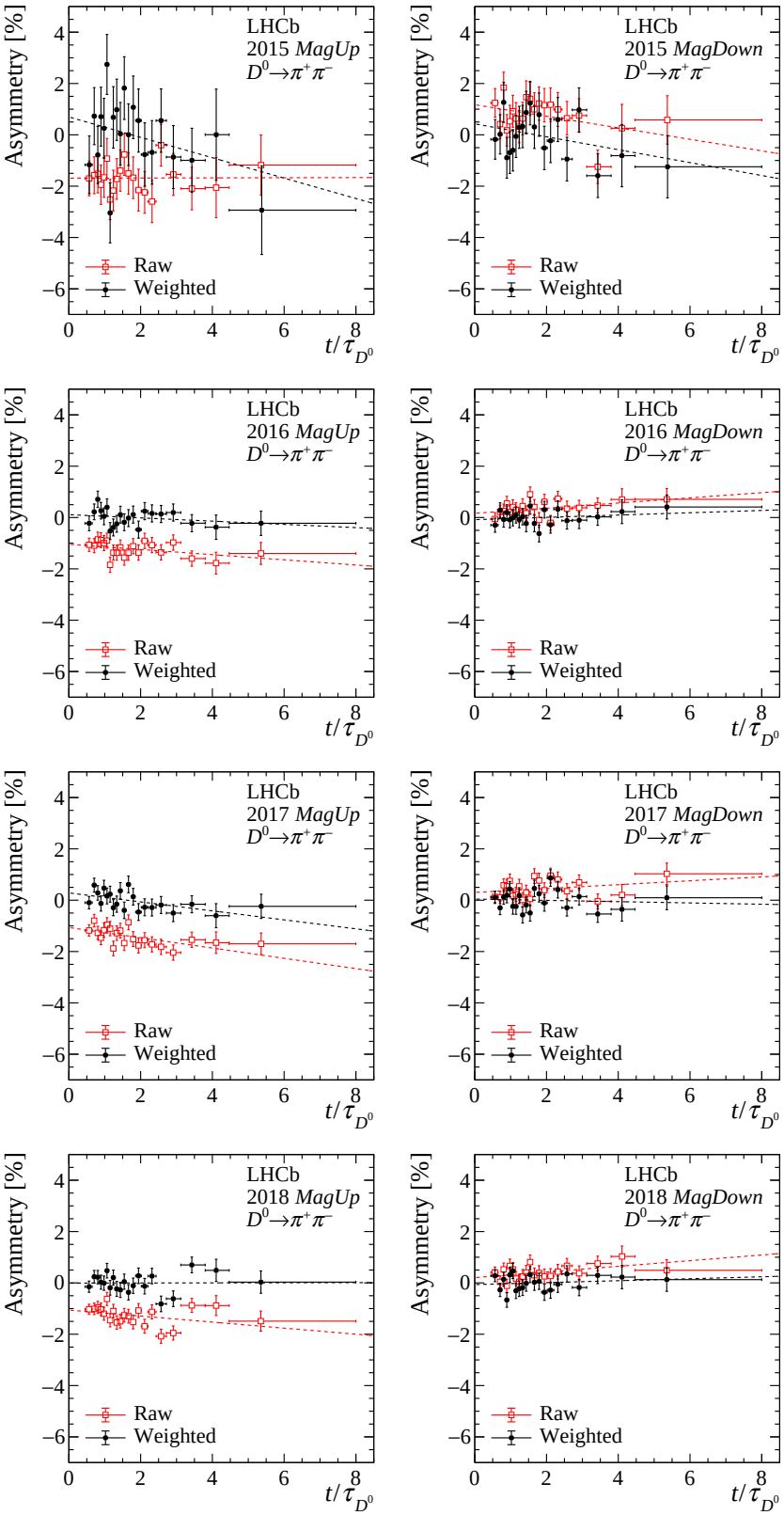

Figure 4: Linear fit to the time-dependent asymmetry of the $D^0 \to \pi^+\pi^-$ sample (red) before and (black) after the kinematic weighting. The contribution of secondary decays from B mesons to the asymmetry is not subtracted.

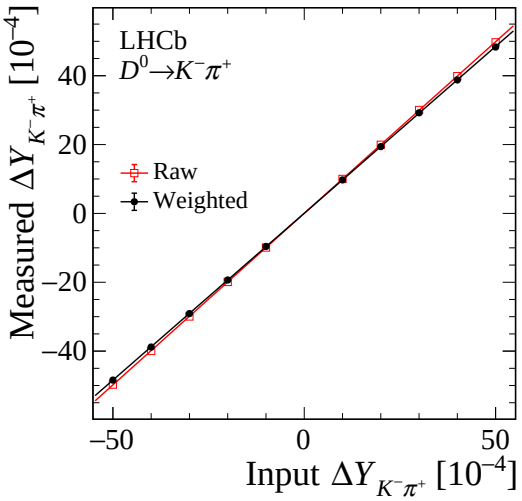

Figure 5: Measured value of $\Delta Y_{K^-\pi^+}$ as a function of the time-dependent asymmetry introduced into the data sample to measure the dilution caused by the kinematic weighting. The result obtained for an introduced asymmetry equal to zero is subtracted from all the other points.

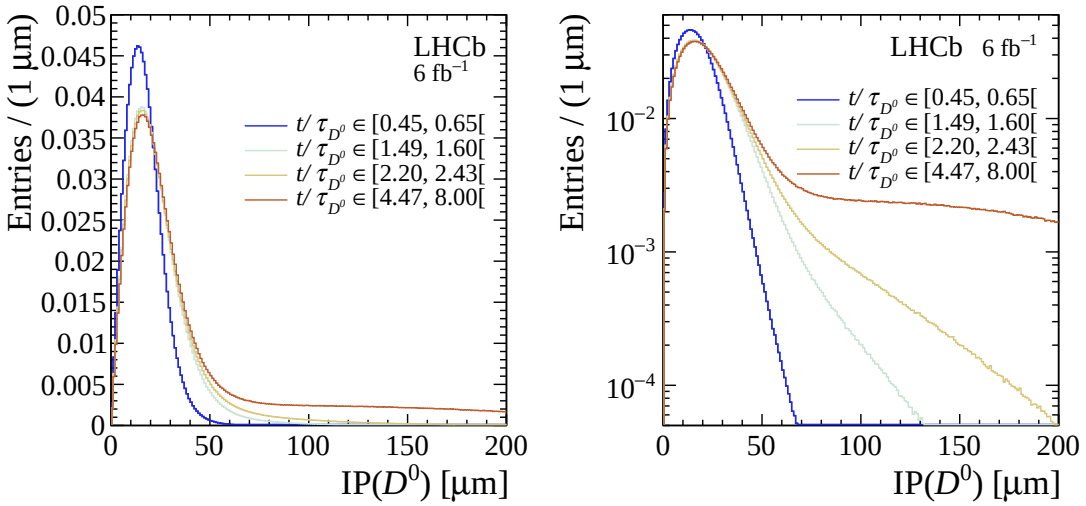

Figure 6: Distributions of the D^0 IP in (left) linear and (right) logarithmic scale, for the 0^{th}, 10^{th}, 15^{th} and 20^{th} bins of decay time. The tails of the distributions at high decay times are due to secondary decays.

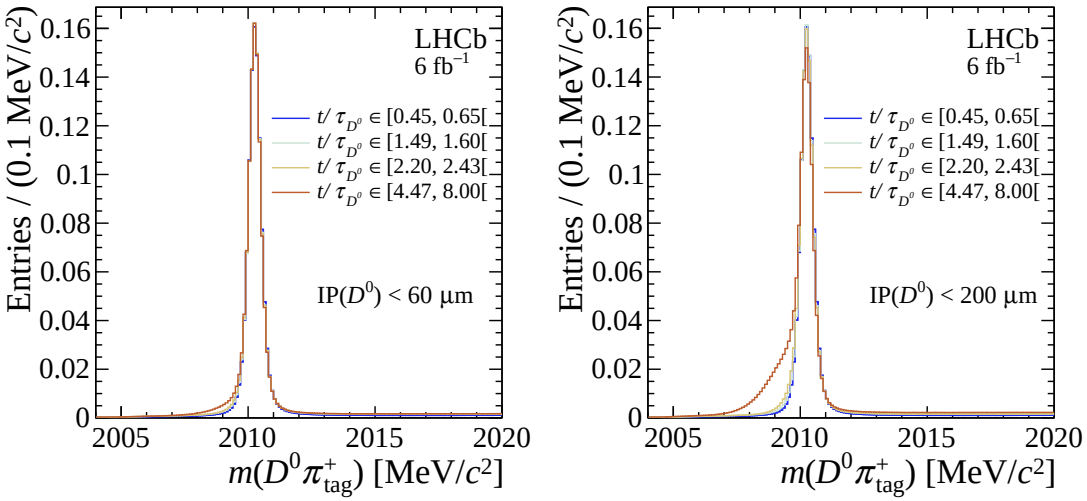

Figure 7: Distributions of $m(D^0\pi^+_{\rm tag})$ with (left) the baseline and (right) a looser requirement on the IP(D^0), for the 0$^{\rm th}$, 10$^{\rm th}$, 15$^{\rm th}$ and 20$^{\rm th}$ bins of decay time. The tail on the left of the $m(D^{*+})$ peak at large decay times is due to secondary decays.

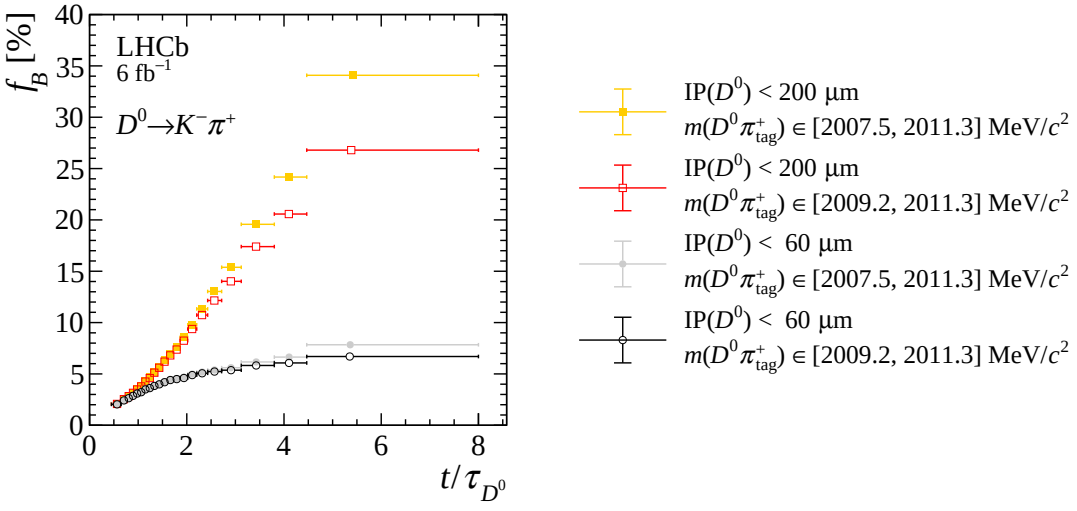

Figure 8: Fraction of secondary decays measured in the template fit of Sect. 6 of the paper. Only the statistical uncertainties are displayed.

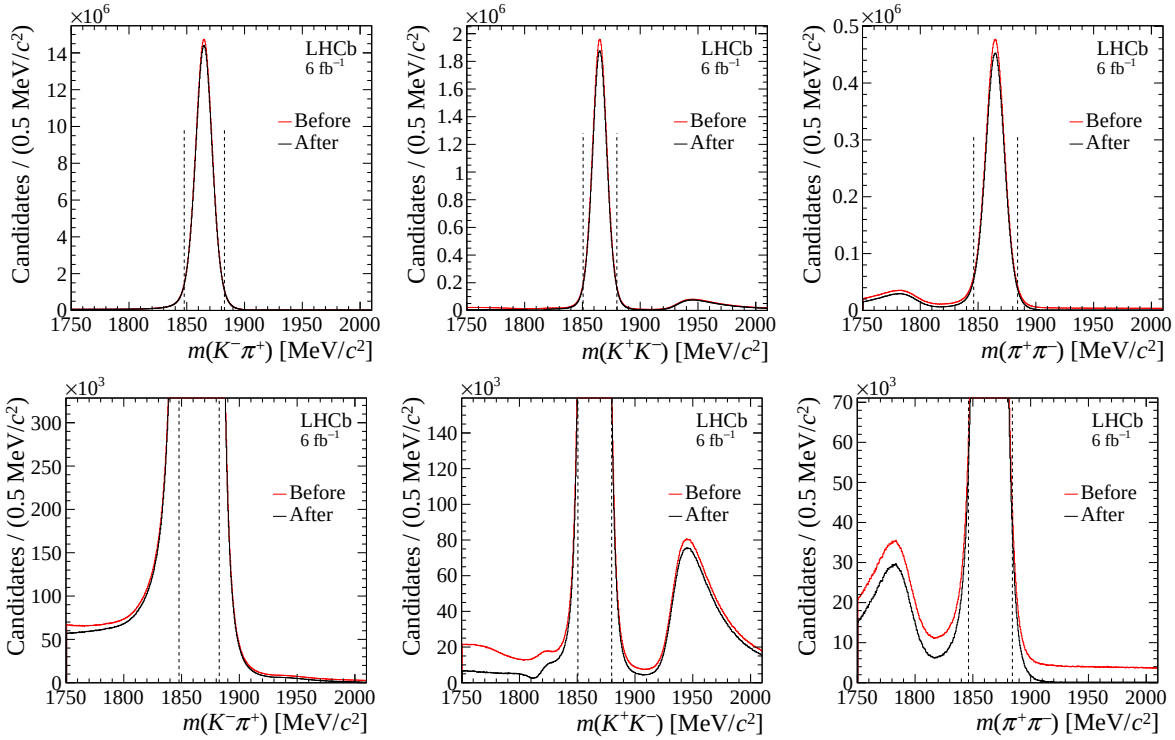

Figure 9: (Top): distribution of the invariant mass $m(h^+h^-)$ of the D^0 candidate (red) before and (black) after the removal of the $m(D^0\pi^+_{\rm tag})$ background. The dashed vertical lines delimit the signal window. (Bottom): Magnification to put in evidence the shape of the residual background under the $m(D^0)$ peak.

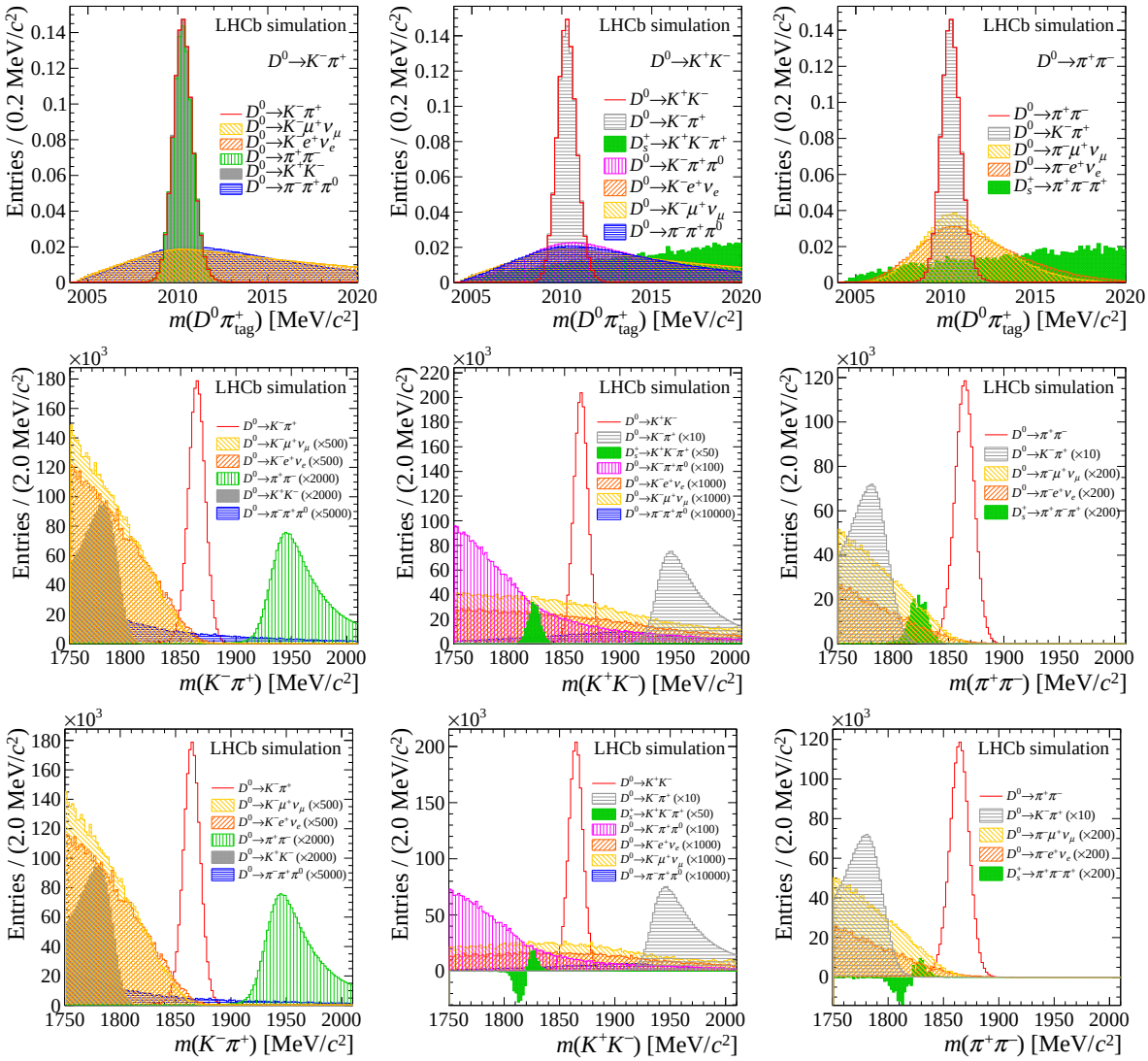

Figure 10: Simulated distributions of (top) $m(D^0\pi^+_{\rm tag})$, (centre) $m(h^+h^-)$ of the candidates in the $m(D^0\pi^+_{\rm tag})$ signal window and (bottom) $m(h^+h^-)$ of selected candidates after the removal of the $m(D^0\pi^+_{\rm tag})$ background, for all signal and background decays. For the $m(h^+h^-)$ plots, the normalisations relative to the signal component are shown in the legend, using the D_s^+–to–D^{*+} cross-section ratio from Ref. [1]. Left, centre and right plots correspond to the $K^-\pi^+$, K^+K^- and $\pi^+\pi^-$ decay channels.

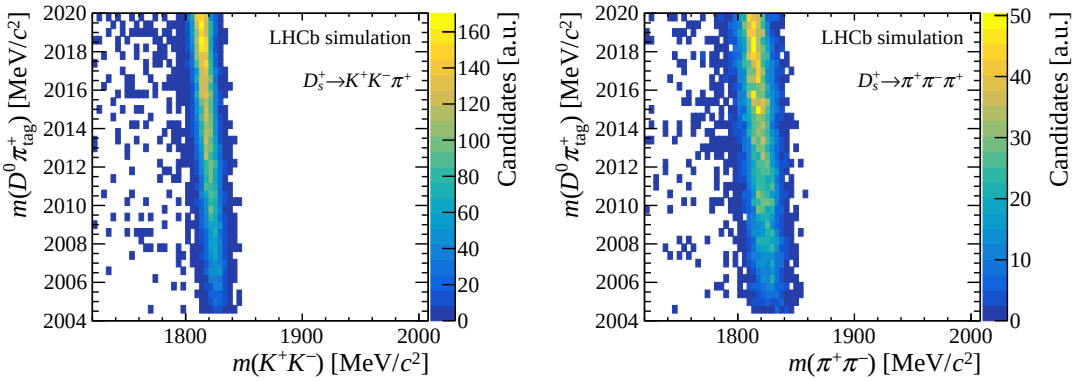

Figure 11: Simulated distribution of (left) $D_s^+ \to K^+K^-\pi^+$ and (right) $D_s^+ \to \pi^+\pi^-\pi^+$ decays in the $m(D^0\pi^+_{\rm tag})$ *vs.* $m(K^+K^-)$ ($m(\pi^+\pi^-)$) plane when they are reconstructed as $D^0 \to K^+K^-$ ($D^0 \to \pi^+\pi^-$) candidates coming from a $D^{*+} \to D^0\pi^+_{\rm tag}$ decay. The plots are produced relying on the `RapidSim` package [2].

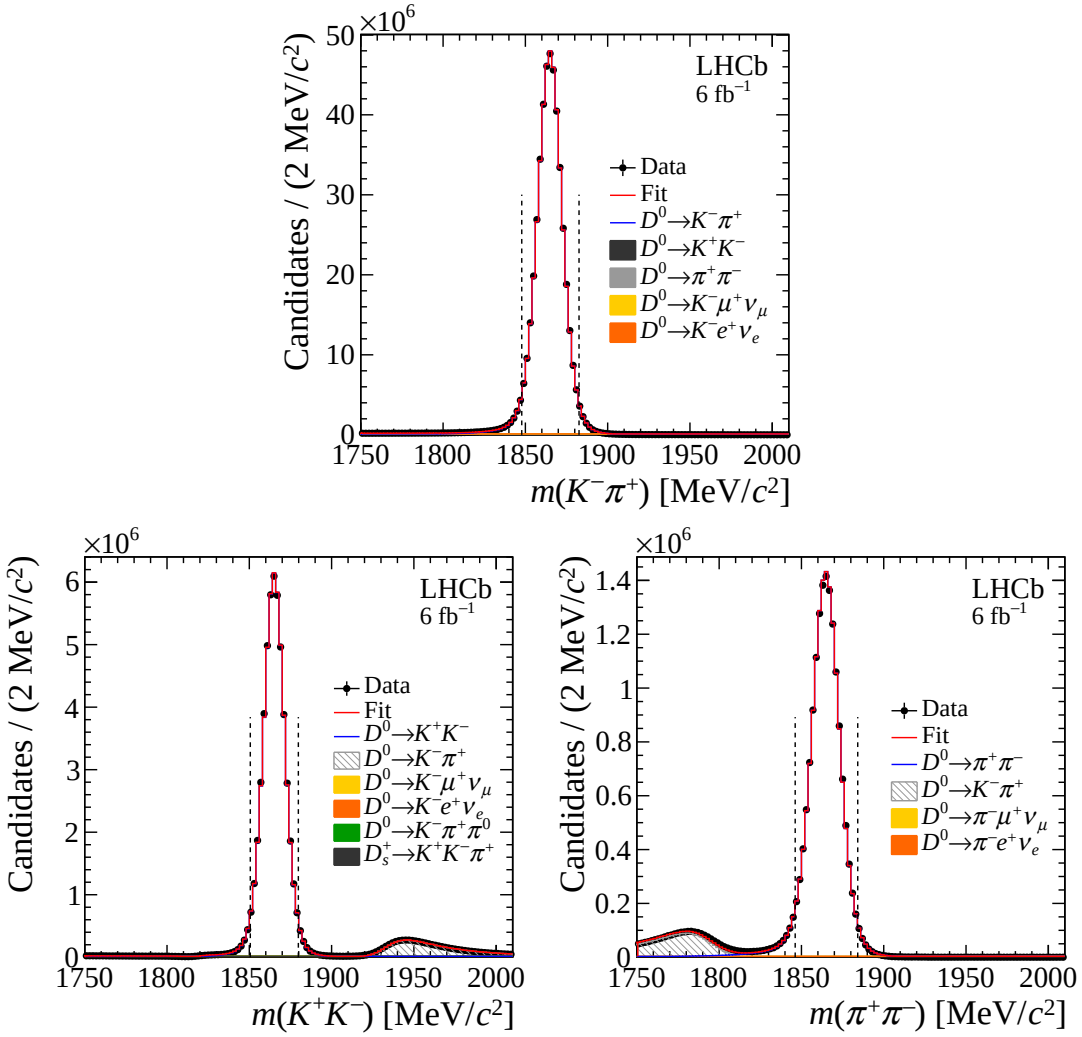

Figure 12: Template fit to the $m(h^+h^-)$ distribution for the (top) $K^-\pi^+$, (left) K^+K^- and (right) $\pi^+\pi^-$ final states, without magnification, as in Fig. 11 of the paper. The vertical dashed lines delimit the signal region.

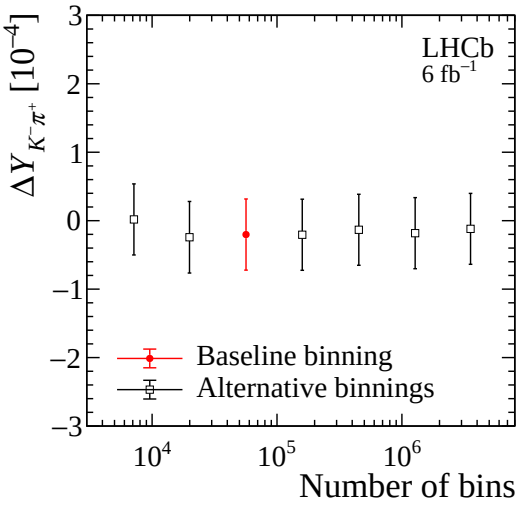

Figure 13: Measurements of $\Delta Y_{K^-\pi^+}$ as a function of the number of bins employed in the kinematic weighting.

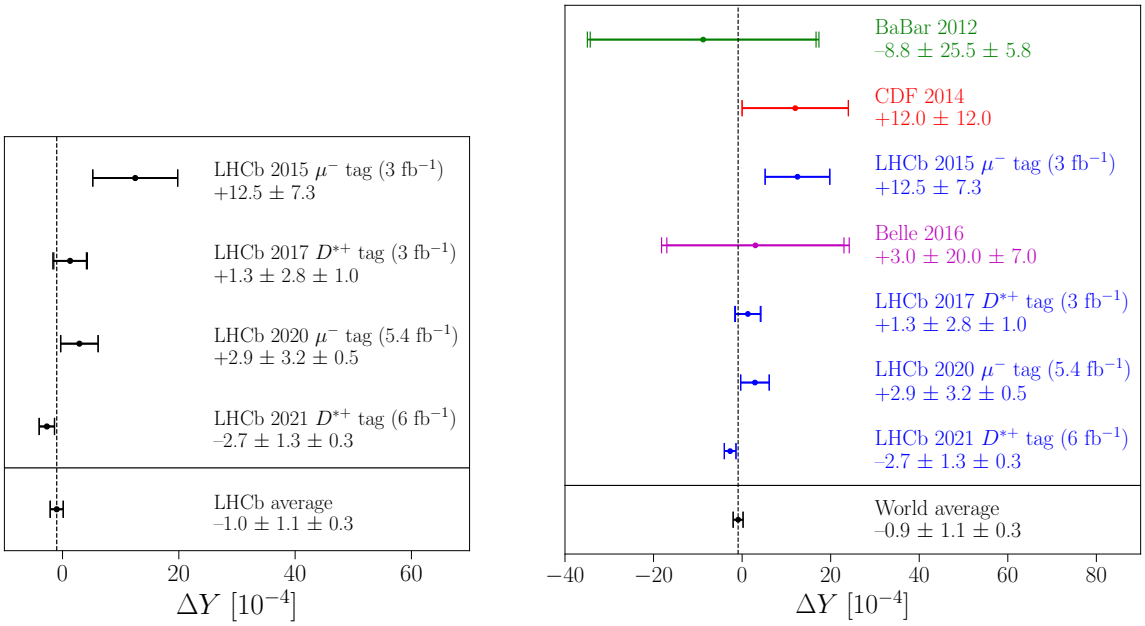

Figure 14: (Left) Summary of the measurements of the parameter ΔY performed by the LHCb experiment, including the present one. The measurements are compatible with each other, with a p-value of 23%. Measurements references, from top to bottom: LHCb 2015 μ^- tag [3], LHCb 2017 D^{*+} tag [4], LHCb 2020 μ^- tag [5]. (Right) Summary of the most precise measurements of the parameter ΔY to date. The measurements are compatible with each other, with a p-value of 38%. Measurements references, in addition to those of the left plot: BaBar 2012 [6], CDF 2014 [7], Belle 2016 [8].

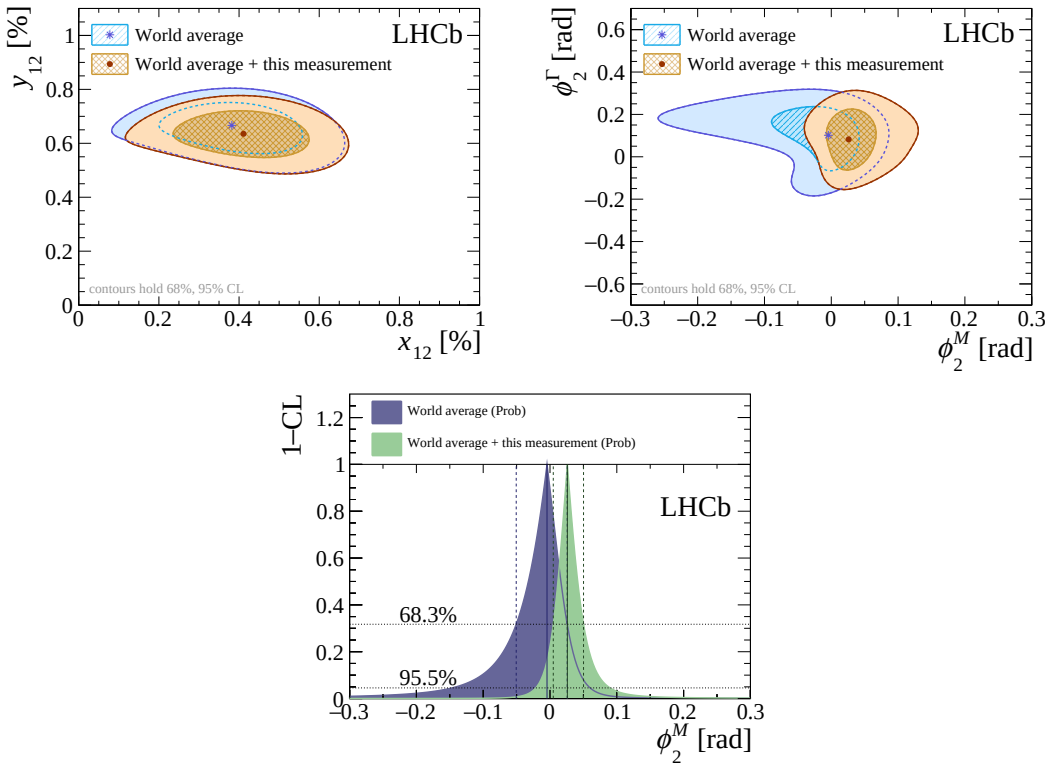

Figure 15: Impact of the present measurement on the knowledge of mixing and time-dependent *CP* violation in D^0 decays. The fit performed to obtain these results is detailed in Refs. [9, 10]; it follows closely the methods of the Heavy Flavor Averaging Group [11] and employs the results in Refs. [3–6, 6–8, 8, 12–26, 26–36].

References

[1] LHCb collaboration, R. Aaij *et al.*, *Measurements of prompt charm production cross-sections in pp collisions at $\sqrt{s}$ =13 TeV*, JHEP **03** (2016) 159, Erratum ibid. **09** (2016) 013, Erratum ibid. **05** (2017) 074, arXiv:1510.01707.

[2] G. A. Cowan, D. C. Craik, and M. D. Needham, *RapidSim: an application for the fast simulation of heavy-quark hadron decays*, Comput. Phys. Commun. **214** (2017) 239, arXiv:1612.07489.

[3] LHCb collaboration, R. Aaij *et al.*, *Measurement of indirect CP asymmetries in $D^0 \to K^-K^+$ and $D^0 \to \pi^-\pi^+$ decays using semileptonic B decays*, JHEP **04** (2015) 043, arXiv:1501.06777.

[4] LHCb collaboration, R. Aaij *et al.*, *Measurement of the CP violation parameter A_Γ in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays*, Phys. Rev. Lett. **118** (2017) 261803, arXiv:1702.06490.

[5] LHCb collaboration, R. Aaij *et al.*, *Updated measurement of decay-time-dependent CP asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays*, Phys. Rev. **D101** (2020) 012005, arXiv:1911.01114.

[6] BaBar collaboration, J. P. Lees *et al.*, *Measurement of D^0–$\overline{D}^0$ mixing and CP violation in two-body D^0 decays*, Phys. Rev. **D87** (2013) 012004, arXiv:1209.3896.

[7] CDF collaboration, T. Aaltonen *et al.*, *Measurement of indirect CP-violating asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays at CDF*, Phys. Rev. **D90** (2014) 111103, arXiv:1410.5435.

[8] Belle collaboration, M. Starič *et al.*, *Measurement of D^0–$\overline{D}^0$ mixing and search for CP violation in $D^0 \to K^+K^-, \pi^+\pi^-$ decays with the full Belle data set*, Phys. Lett. **B753** (2016) 412, arXiv:1509.08266.

[9] T. Pajero and M. J. Morello, *Mixing and CP violation in $D^0 \to K^-\pi^+$ decays*, arXiv:2106.02014.

[10] T. Pajero, *Search for time-dependent CP violation in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays*, PhD thesis, Scuola Normale Superiore, 2021, CERN-THESIS-2020-231.

[11] Heavy Flavor Averaging Group, Y. Amhis *et al.*, *Averages of b-hadron, c-hadron, and τ-lepton properties as of 2018*, Eur. Phys. J. **C81** (2021) 226, arXiv:1909.12524, updated results and plots available at https://hflav.web.cern.ch.

[12] E791 collaboration, E. M. Aitala *et al.*, *Measurements of lifetimes and a limit on the lifetime difference in the neutral D meson system*, Phys. Rev. Lett. **83** (1999) 32, arXiv:hep-ex/9903012.

[13] Belle collaboration, A. Zupanc *et al.*, *Measurement of y_{CP} in D^0 meson decays to the $K^0_S K^+K^-$ final state*, Phys. Rev. **D80** (2009) 052006, arXiv:0905.4185.

[14] BESIII collaboration, M. Ablikim *et al.*, *Measurement of y_{CP} in $D^0 - \overline{D}^0$ oscillation using quantum correlations in $e^+e^- \to D^0\overline{D}^0$ at $\sqrt{s}$ = 3.773 GeV*, Phys. Lett. **B744** (2015) 339, arXiv:1501.01378.

[15] FOCUS collaboration, J. M. Link *et al.*, *A Measurement of lifetime differences in the neutral D meson system*, Phys. Lett. **B485** (2000) 62, arXiv:hep-ex/0004034.

[16] CLEO collaboration, S. E. Csorna *et al.*, *Lifetime differences, direct CP violation and partial widths in D^0 meson decays to K^+K^- and $\pi^+\pi^-$*, Phys. Rev. **D65** (2002) 092001, arXiv:hep-ex/0111024.

[17] LHCb collaboration, R. Aaij *et al.*, *Measurement of the charm-mixing parameter y_{CP}*, Phys. Rev. Lett. **122** (2019) 011802, arXiv:1810.06874.

[18] Belle collaboration, M. Nayak *et al.*, *Measurement of the charm-mixing parameter y_{CP} in $D^0 \to K^0_S\omega$ decays at Belle*, Phys. Rev. **D102** (2020) 071102, arXiv:1912.10912.

[19] LHCb collaboration, R. Aaij *et al.*, *Measurement of mixing and CP violation parameters in two-body charm decays*, JHEP **04** (2012) 129, arXiv:1112.4698.

[20] E791 collaboration, E. M. Aitala *et al.*, *Search for $D^0 - \overline{D}^0$ mixing in semileptonic decay modes*, Phys. Rev. Lett. **77** (1996) 2384, arXiv:hep-ex/9606016.

[21] CLEO collaboration, C. Cawlfield *et al.*, *Limits on neutral D mixing in semileptonic decays*, Phys. Rev. **D71** (2005) 077101, arXiv:hep-ex/0502012.

[22] BaBar collaboration, B. Aubert *et al.*, *Search for $D^0 - \bar{D}^0$ mixing using semileptonic decay modes*, Phys. Rev. **D70** (2004) 091102, arXiv:hep-ex/0408066.

[23] BaBar collaboration, B. Aubert *et al.*, *Search for $D^0 - \overline{D}^0$ mixing using doubly flavor tagged semileptonic decay modes*, Phys. Rev. **D76** (2007) 014018, arXiv:0705.0704.

[24] Belle collaboration, U. Bitenc *et al.*, *Improved search for D^0–$\bar{D}^0$ mixing using semileptonic decays at Belle*, Phys. Rev. **D77** (2008) 112003, arXiv:0802.2952.

[25] LHCb collaboration, R. Aaij *et al.*, *First observation of $D^0 - \overline{D}^0$ oscillations in $D^0 \to K^+\pi^+\pi^-\pi^-$ decays and a measurement of the associated coherence parameters*, Phys. Rev. Lett. **116** (2016) 241801, arXiv:1602.07224.

[26] BaBar collaboration, B. Aubert *et al.*, *Evidence for $D^0 - \overline{D}^0$ Mixing*, Phys. Rev. Lett. **98** (2007) 211802, arXiv:hep-ex/0703020.

[27] Belle collaboration, B. R. Ko *et al.*, *Observation of $D^0 - \bar{D}^0$ Mixing in e^+e^- Collisions*, Phys. Rev. Lett. **112** (2014) 111801, Erratum ibid. **112** (2014) 139903, arXiv:1401.3402.

[28] CDF collaboration, T. A. Aaltonen *et al.*, *Observation of D^0–$\bar{D}^0$ Mixing Using the CDF II Detector*, Phys. Rev. Lett. **111** (2013) 231802, arXiv:1309.4078.

[29] LHCb collaboration, R. Aaij *et al.*, *Updated determination of D^0–$\overline{D}^0$ mixing and CP violation parameters with $D^0 \to K^+\pi^-$ decays*, Phys. Rev. **D97** (2018) 031101, arXiv:1712.03220.

[30] CLEO collaboration, D. M. Asner *et al.*, *Updated measurement of the strong phase in $D^0 \to K^+\pi^-$ decay using quantum correlations in $e^+e^- \to D^0\bar{D}^0$ at CLEO*, Phys. Rev. **D86** (2012) 112001, arXiv:1210.0939.

[31] BESIII collaboration, M. Ablikim *et al.*, *Measurement of the $D \to K^-\pi^+$ strong phase difference in $\psi(3770) \to D^0\overline{D}^0$*, Phys. Lett. **B734** (2014) 227, arXiv:1404.4691.

[32] BaBar collaboration, P. del Amo Sanchez *et al.*, *Measurement of $D^0 - \overline{D}^0$ mixing parameters using $D^0 \to K^0_S\pi^+\pi^-$ and $D^0 \to K^0_S K^+K^-$ decays*, Phys. Rev. Lett. **105** (2010) 081803, arXiv:1004.5053.

[33] BaBar collaboration, J. P. Lees *et al.*, *Measurement of the neutral D meson mixing parameters in a time-dependent amplitude analysis of the $D^0 \to \pi^+\pi^-\pi^0$ decay*, Phys. Rev. **D93** (2016) 112014, arXiv:1604.00857.

[34] Belle collaboration, T. Peng *et al.*, *Measurement of $D^0 - \bar{D}^0$ mixing and search for indirect CP violation using $D^0 \to K^0_S\pi^+\pi^-$ decays*, Phys. Rev. **D89** (2014) 091103, arXiv:1404.2412.

[35] LHCb collaboration, R. Aaij *et al.*, *Measurement of the mass difference between neutral charm-meson eigenstates*, Phys. Rev. Lett. **122** (2019) 231802, arXiv:1903.03074.

[36] BaBar collaboration, B. Aubert *et al.*, *Measurement of $D^0 - \bar{D}^0$ mixing from a time-dependent amplitude analysis of $D^0 \to K^+\pi^-\pi^0$ decays*, Phys. Rev. Lett. **103** (2009) 211801, arXiv:0807.4544.