New results on CPV in charm & bottom at LHCb

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Outline

- CP violation in the Standard Model
- The LHCb detector and news from Upgrade-I commissioning
- Latest results on direct CP violation in beauty and charm decays
  - $B^{+} \to hh'h'$ (model independent and resonances)
  - $D^{0} \to K^{-}K^{+}$(main focus of today's talk)
- LHCb combination on the CKM parameter γ and charm CPV and mixing parameters
- Conclusions

CP violation in the Standard Model

CP violation in the Standard Model

The weak interactions of quarks are described in terms of the unitary Cabibbo–Kobayashi–Maskawa (CKM) matrix.

CP violation implies a complex phase in the CKM matrix

$$V_{CKM} = \begin{pmatrix} V_{ud} V_{us} V_{ub} \\ V_{cd} V_{cs} V_{cb} \\ V_{td} V_{ts} V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

CP violation is violated if $\eta \neq 0$

$$|V_{CKM}| \simeq \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

The complex components reside only in V_{ub} and V_{td} at λ^3 order

→ Higher order (λ^5) also in V_{cd} and V_{ts}

CP violation in the decay (or direct CPV)

CP Violation in the decay consists of a difference in decay amplitude between the decay of a hadron $P \rightarrow f$ and its CP-conjugate $\bar{P} \rightarrow \bar{f}$

$$a_f^d = \frac{|A_f|^2 - |\bar{A}_{\bar{f}}|^2}{|A_f|^2 + |\bar{A}_{\bar{f}}|^2}$$

CPV can be observed, if the total amplitude of $P \rightarrow f$ (or $\bar{P} \rightarrow \bar{f}$) consists of two interfering amplitudes with difference phases

$$A_f = A_1 e^{i\phi_1} e^{i\delta_1} + A_2 e^{i\phi_2} e^{i\delta_2}$$
$$\bar{A}_{\bar{f}} = A_1\, e^{-i\phi_1} e^{i\delta_1} + A_2 e^{-i\phi_2} e^{i\delta_2}$$
$$|A_f|^2 - |\bar{A}_{\bar{f}}|^2 = 2|\mathrm{A}_1||\mathrm{A}_2|\sin(\phi_1 - \phi_2)\sin(\delta_1 - \delta_2)$$

Only weak phases change under the action of the CP operator

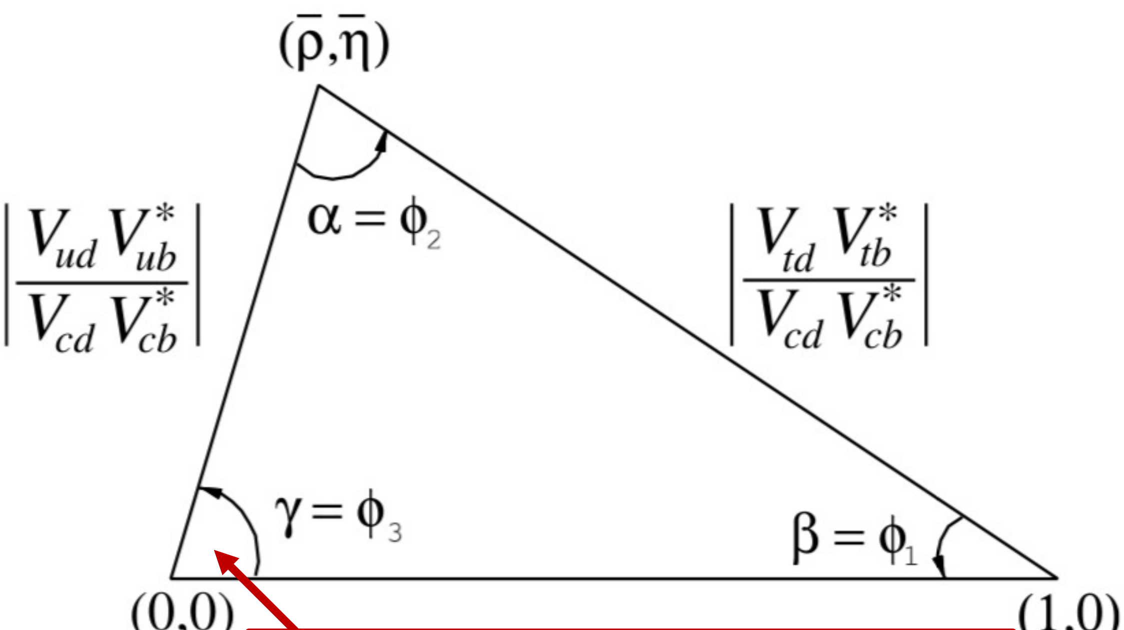
Strong phases can enhance the obserbed CP violation

The unitarity triangle

The CKM matrix is unitary implies constraints on CKM elements

These constraints are usually expressed in terms of the Unitarity Triangle

$$1 - \frac{|V_{ud}||V_{ub}^*|}{|V_{cd}||V_{cb}^*|} e^{i\gamma} - \frac{|V_{td}||V_{tb}^*|}{|V_{cd}||V_{cb}^*|} e^{-i\beta} = 0$$



$$\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

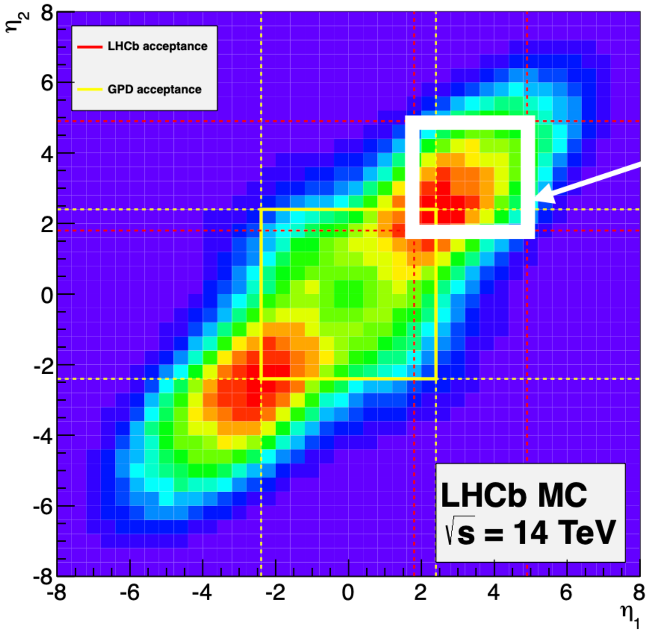
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

$$\beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

Angle γ : CP violation in $B \to DK$, $B \to D\pi$ decays

The LHCb detector

The LHCb principle

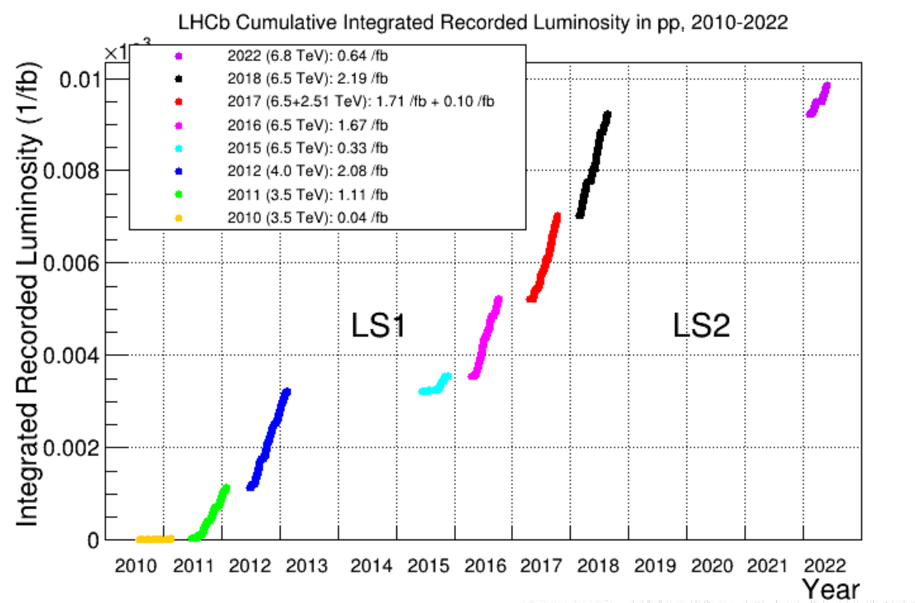


This region:
25% of $b\bar{b}$

$\sigma(\bar{b}b)(7\ \mathrm{TeV}) \sim 295\ \mu\mathrm{b}$
$\sigma(\bar{b}b)(13\ \mathrm{TeV}) \sim 590\ \mu\mathrm{b}$
$\sigma(\bar{c}c)(7\ \mathrm{TeV}) \sim 1420\ \mu\mathrm{b}$
$\sigma(\bar{c}c)(13\ \mathrm{TeV}) \sim 2840\ \mu\mathrm{b}$

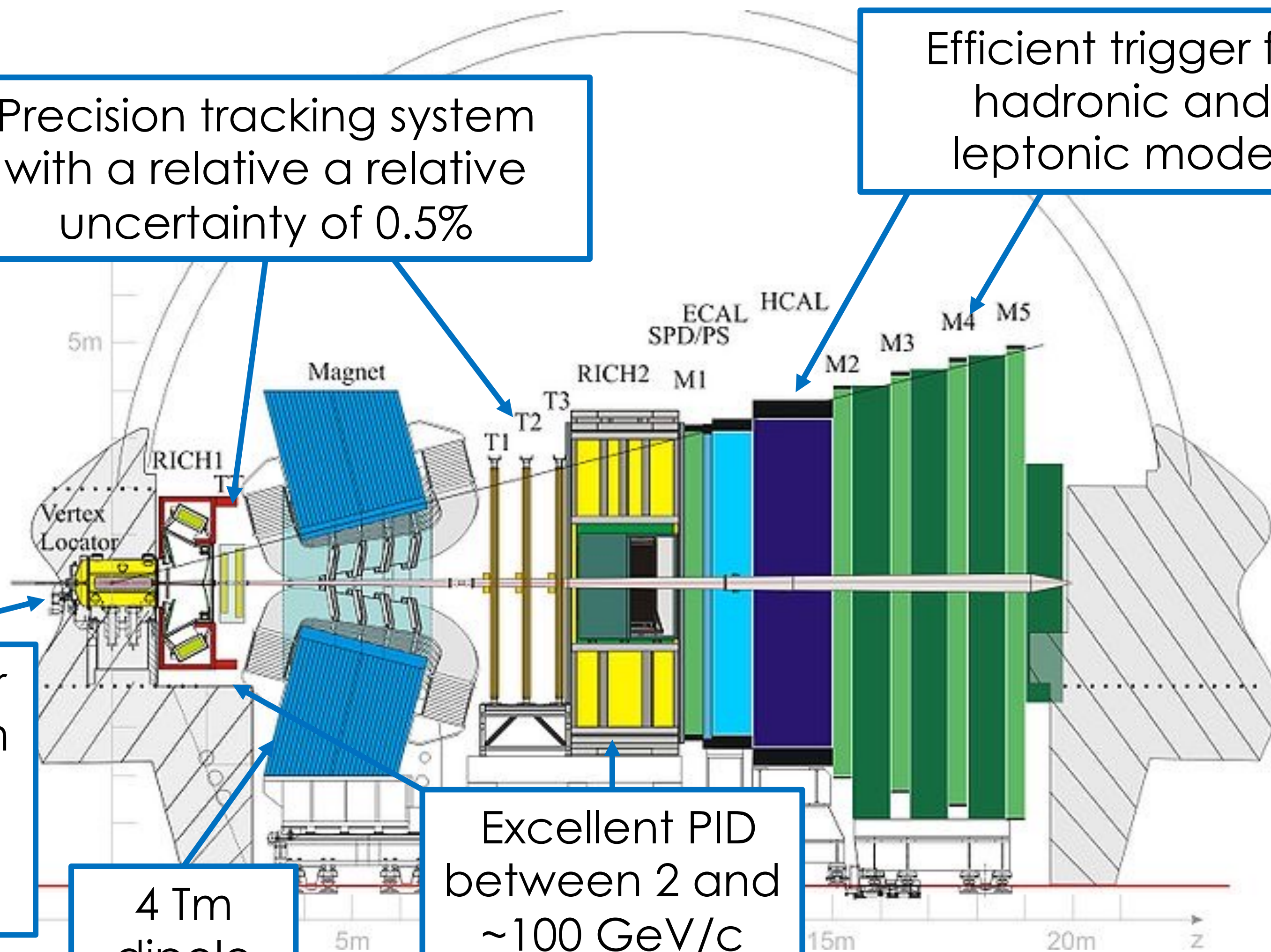
large cross-section of b and c hadrons in proton-proton collisions

LHCb is designed as a forward spectrometer acceptance $2 < \eta < 5$



$\int \mathcal{L}dt = 9\ \mathrm{fb}^{-1}$ recorded during Run1+Run2

The LHCb detector in RUN1 and RUN2



Precision tracking system with a relative a relative uncertainty of 0.5%

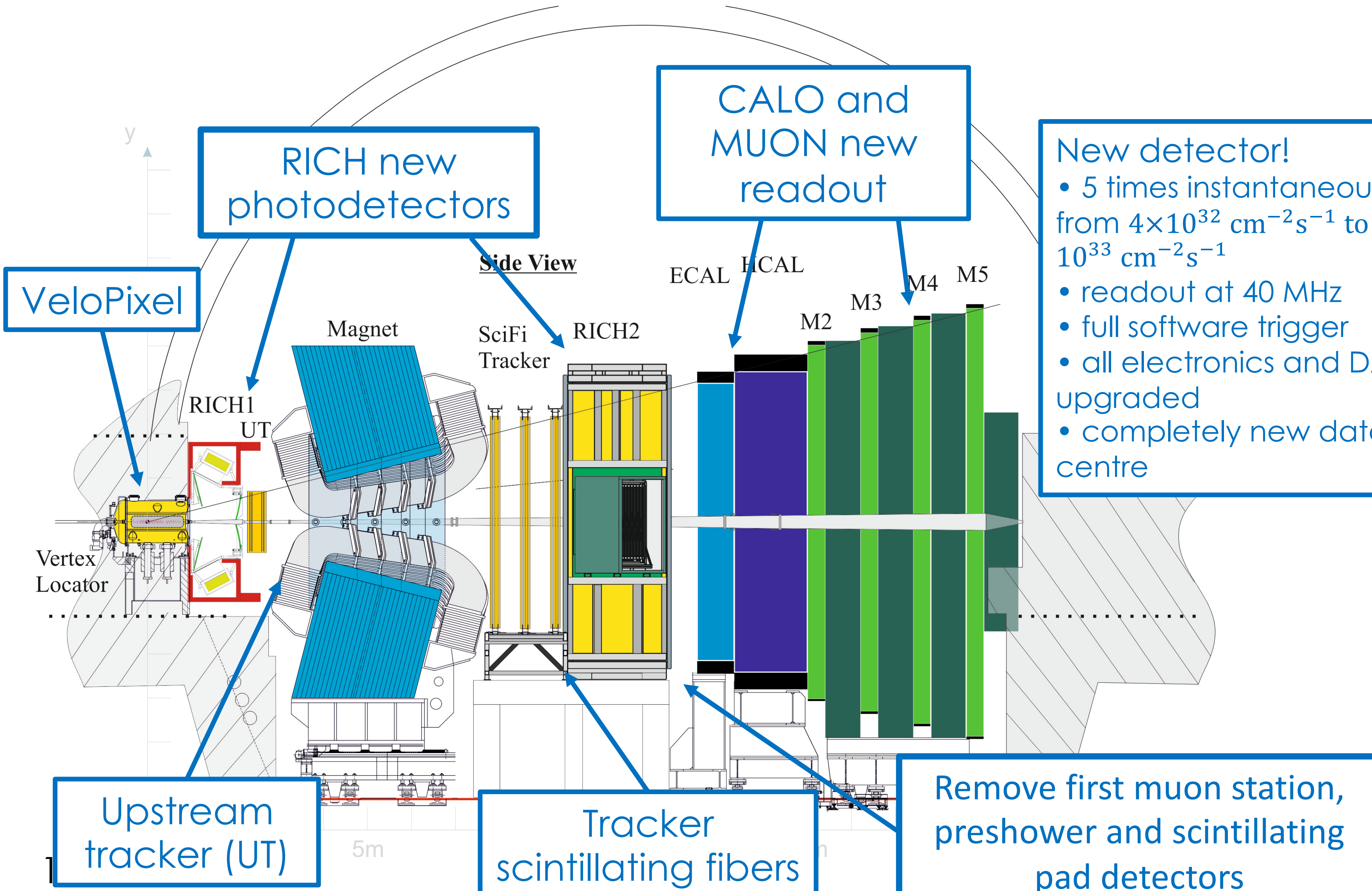
Efficient trigger for hadronic and leptonic modes

VErtex Lcator at 8 mm from beam
$\sigma(t) \approx 45$ fs
$\sigma(IP) \approx 20$ μm

4 Tm dipole magnet

Excellent PID between 2 and ~100 GeV/c
$\epsilon(\pi \to K) \approx 3\%$

The LHCb-upgrade-I detector

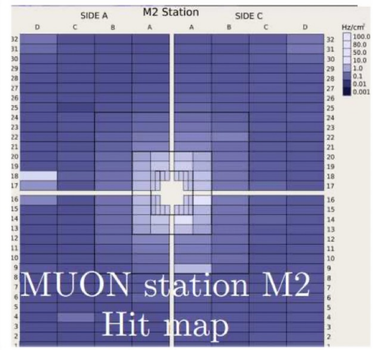


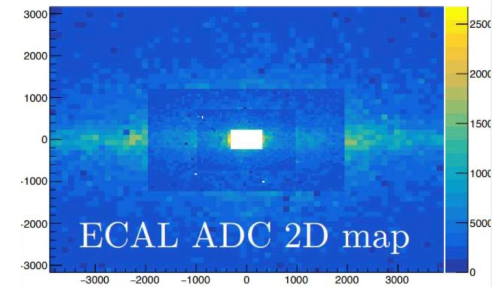
New detector!

- 5 times instantaneous lumi from $4\times10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ to $2\times10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- readout at 40 MHz
- full software trigger
- all electronics and DAQ upgraded
- completely new data centre

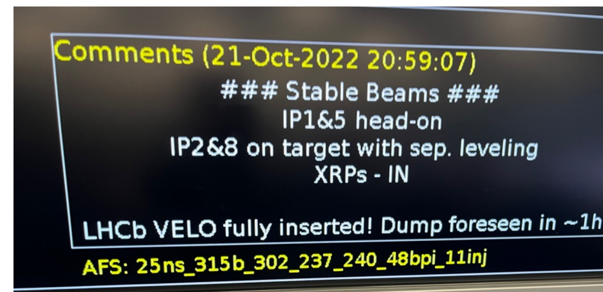
Run3 commisioning

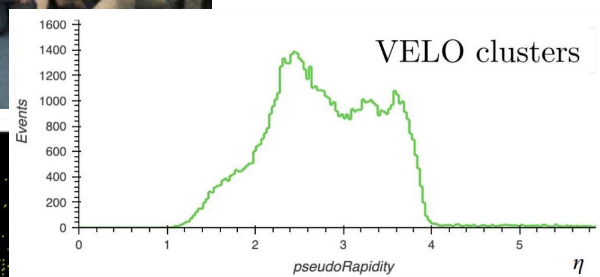
5-July-2022
First collisions at the world-record energy

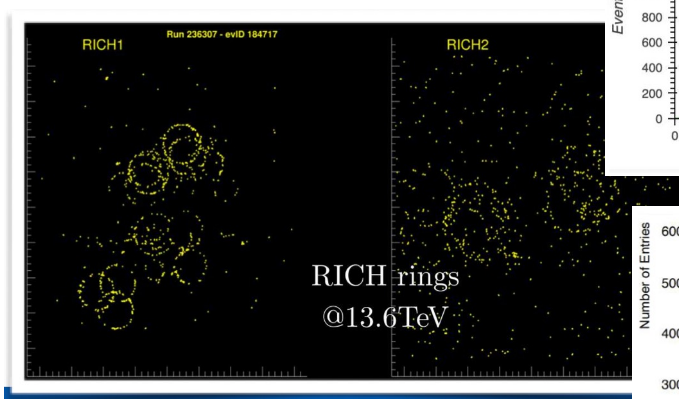


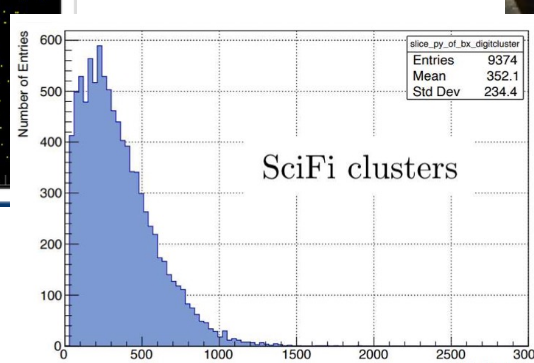


21-Oct-2022
First VELO
closing









Latest results on direct CP violation in beauty and charm decays

Direct CP violation in charmless three-body decays of $B^{\pm}$ mesons
LHCb-PAPER-2021-049
Search for direct CP violation in charged charmless $B \to PV$ decays
LHCb-PAPER-2021-050
Measurement of time-integrated CP asymmetry in $D^0 \to K^- K^+$ decays
LHCb-PAPER-2022-044

Charmless three-body decays $B^+ \to hh'h'$

LHCb-PAPER-2021-049

Analysis based on $\int \mathcal{L}\mathrm{dt} = 5.9\ \mathrm{fb}^{-1}$

$B^\pm \to \pi^\pm\pi^+\pi^-$
$B^\pm \to K^\pm K^+ K^-$
$B^\pm \to \pi^\pm K^- K^+$
$B^\pm \to K^\pm\pi^+\pi^-$

Phase-space integrated CP asymmetries and CP asymmetries in specific regions of the Dalitz plots

CPV already observed in previous LHCb analysis

[Phys. Rev. D101 (2020) 012006, Phys. Rev. Lett. 124 (2020) 031801]

[Phys. Rev. Lett. 123 (2019) 231802]

[Phys. Rev. Lett. 112 (2014) 011801, Phys. Rev. D90 (2014) 112004]

Long-distance effects, interference between P and S-wave and $\pi\pi \to KK$ rescattering are the main sources of CP violation

[Prog. Part. Nucl. Phys. 114 (2020) 103808]

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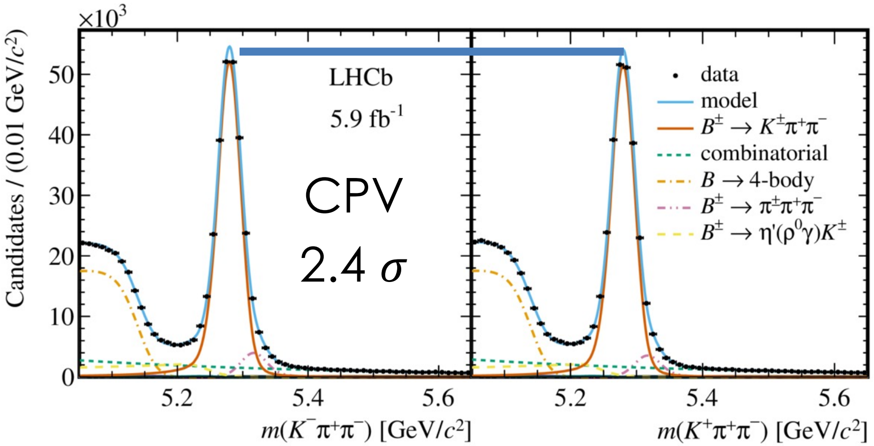
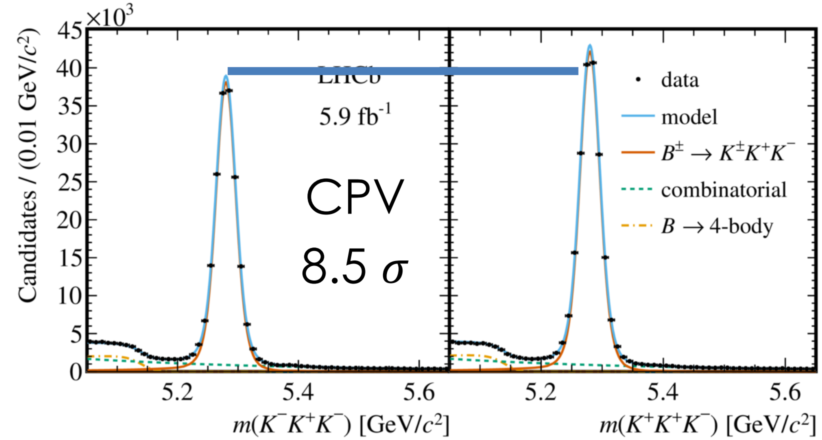
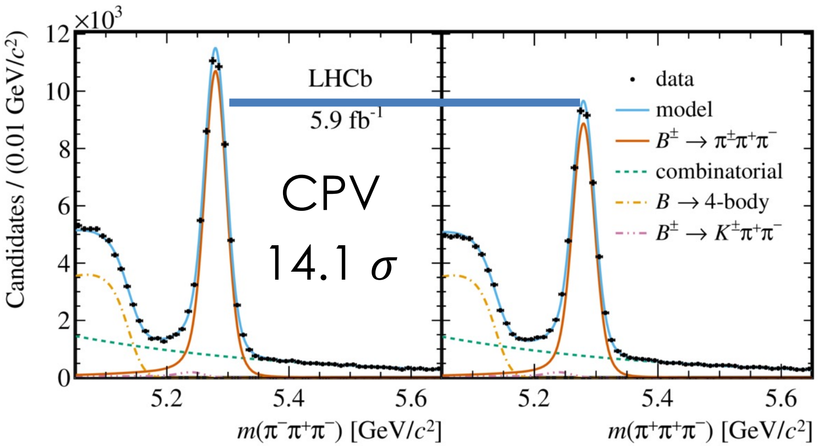
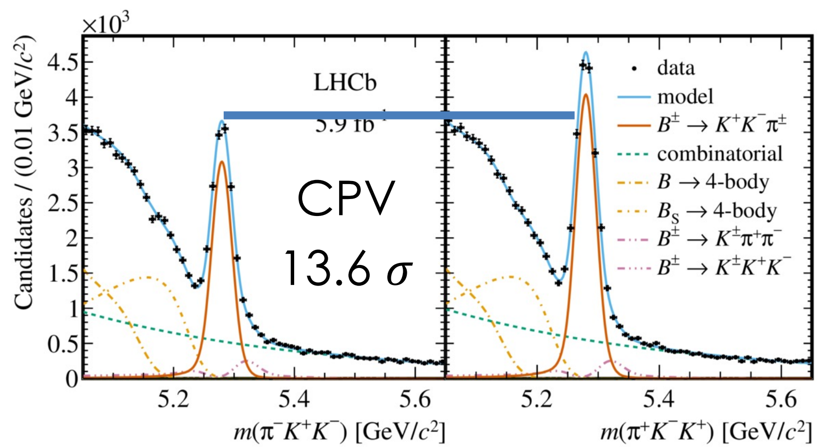
Phase-space-integrated CP-violation









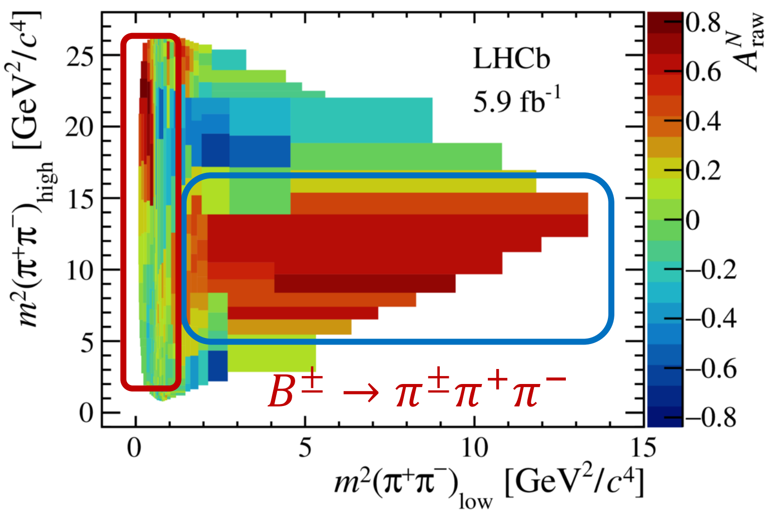
Decay mode	Total yield
$B^\pm \to K^\pm\pi^+\pi^-$	$499\,200 \pm 900$
$B^\pm \to K^\pm K^+K^-$	$365\,000 \pm 1000$
$B^\pm \to \pi^\pm\pi^+\pi^-$	$101\,000 \pm 500$
$B^\pm \to \pi^\pm K^+K^-$	$32\,470 \pm 300$

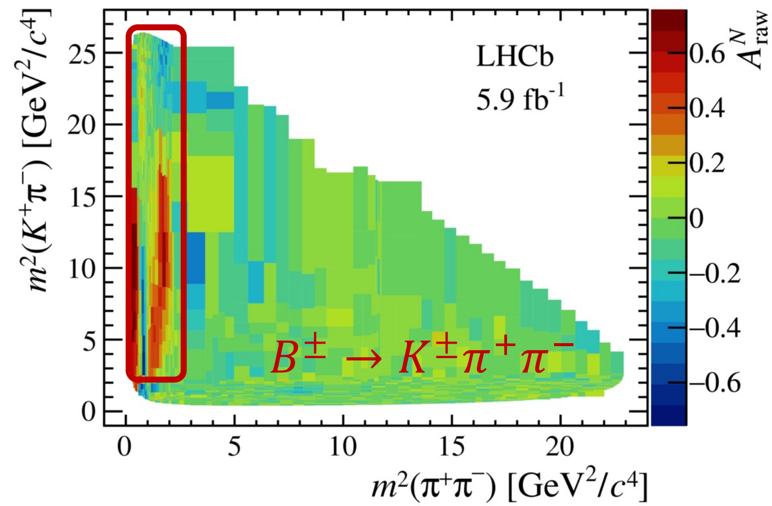
$$A_{CP}(B^\pm \to K^\pm\pi^+\pi^-) = +0.011 \pm 0.002 \pm 0.003 \pm 0.003$$
$$A_{CP}(B^\pm \to K^\pm K^+K^-) = -0.037 \pm 0.002 \pm 0.002 \pm 0.003$$
$$A_{CP}(B^\pm \to \pi^\pm\pi^+\pi^-) = +0.080 \pm 0.004 \pm 0.003 \pm 0.003$$
$$A_{CP}(B^\pm \to \pi^\pm K^+K^-) = -0.114 \pm 0.007 \pm 0.003 \pm 0.003$$

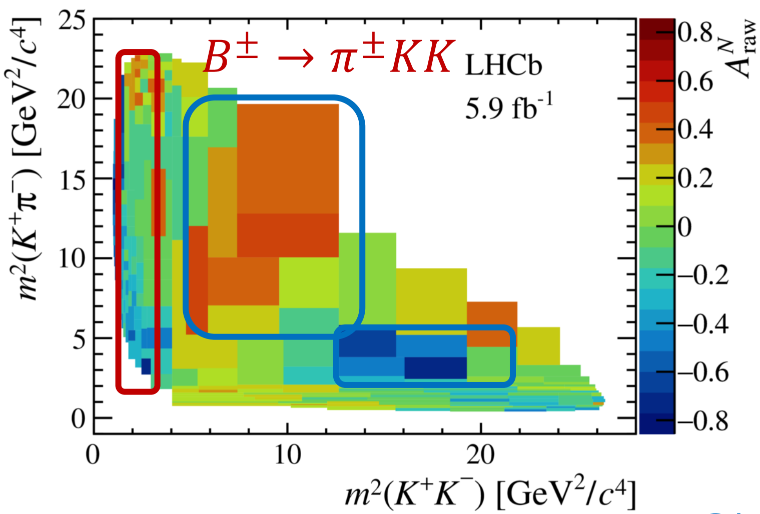
Localised CP-violation

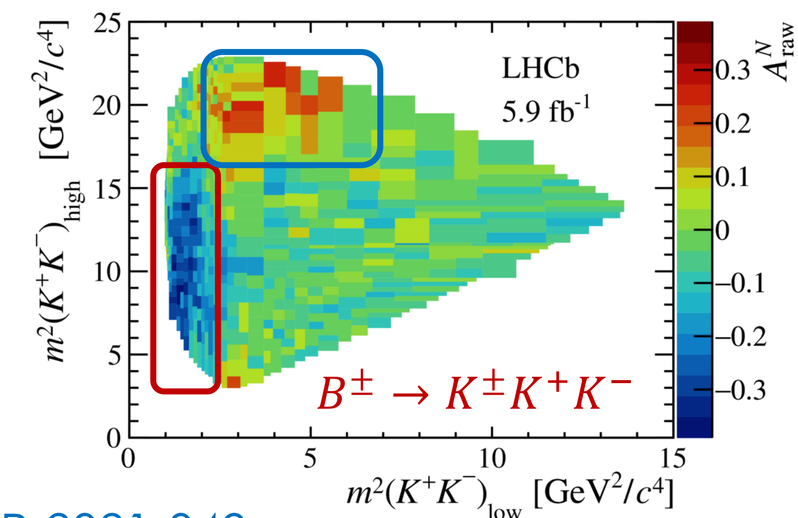
$$A_{raw} = \frac{N^i_{B^-} - N^i_{B^+}}{N^i_{B^-} + N^i_{B^+}}$$

Rich pattern of large and localized asymmetry from interference between the resonant contributions, and possible $\pi\pi \leftrightarrow KK$ rescattering









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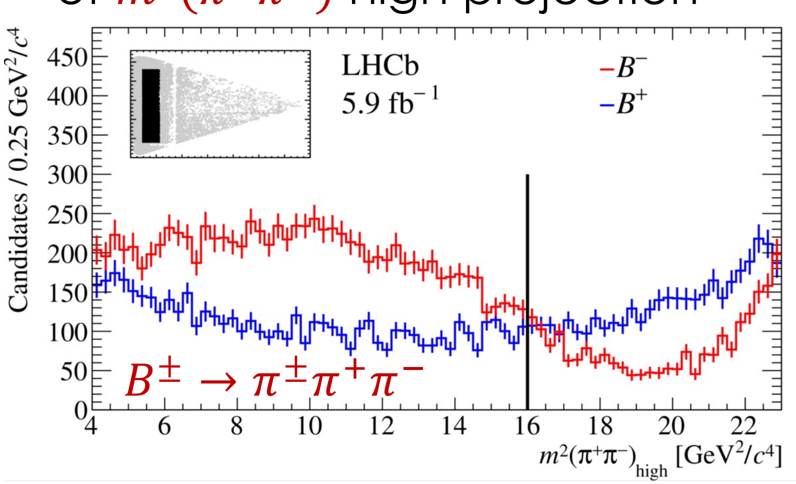
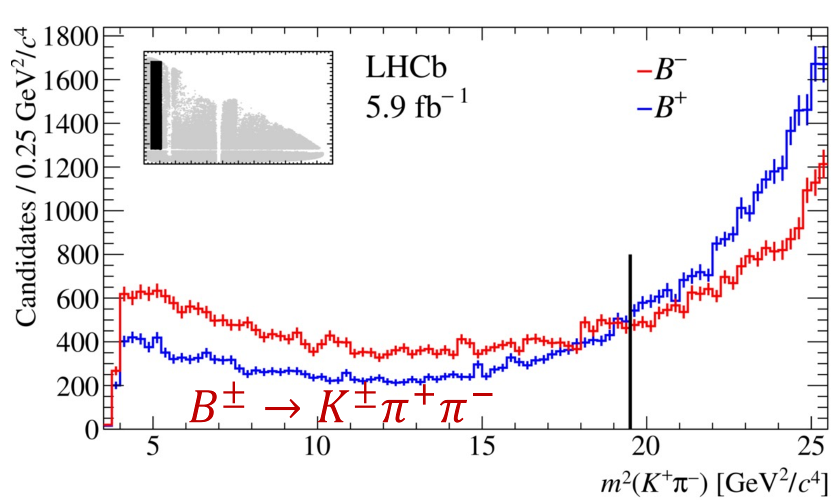
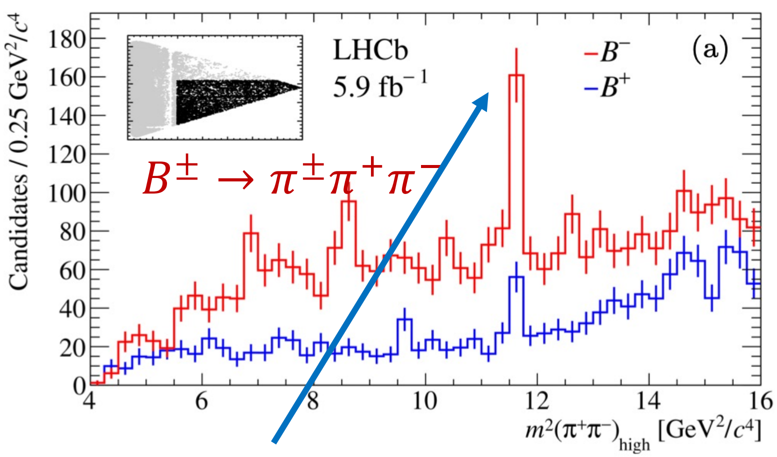
Localised CP-violation

CP asymmetry presents positively and negatively in left and right region of $m^2(\pi^+\pi^-)$ high projection

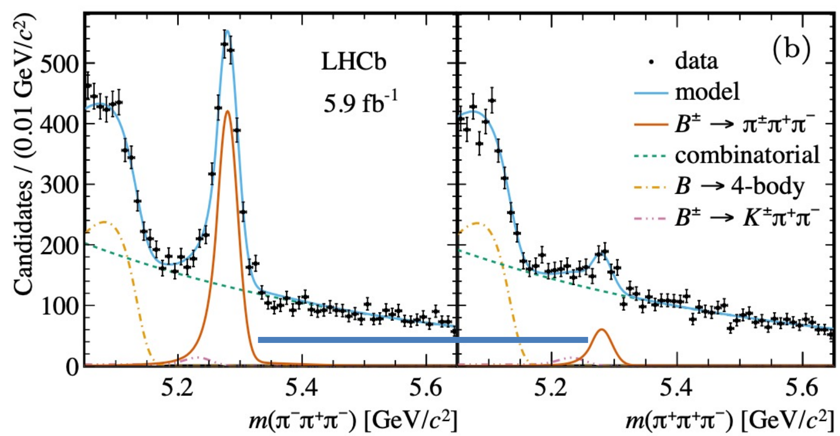




Large CP asymmetry $A_{CP} = (74.5 \pm 2.7 \pm 1.8)\%$ in the charmonium region



$\chi_{C0}(1P)$



CP violation in $B \to PV$ decays

$B \to PV$ decays are quasi-two-body decays that result in three-body final states due to V decays

Given the large phase space of these B-meson decays, different types of resonant contributions are allowed where the vector resonances interfere with other resonant components

The CP asymmetry is measured using RUN2 data corresponding to $5.9\ \text{fb}^{-1}$ for the following decays

$B^{\pm} \to \overset{(-)}{K}{}^{*}(892)^{0}\pi^{\pm}$ from $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$
$B^{\pm} \to \phi(1020)\pi^{\pm}$ from $B^{\pm} \to K^{\pm}K^{+}K^{-}$
$B^{\pm} \to \rho(770)^{0}\pi^{\pm}$. from $B^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$
$B^{\pm} \to K^{*}(892)^{0}K^{\pm}$ from $B^{\pm} \to \pi^{\pm}K^{+}K^{-}$

Results

For isolated vector resonance the squared module of the amplitude is given by

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

- $p_0^\pm$: CPV from scalar
- $p_1^\pm \cos\theta(m_V^2, s_\perp)$: Related to CPV in the Interference scalar vector
- $p_2^\pm \cos^2\theta(m_V^2, s_\perp)$: CPV from vector

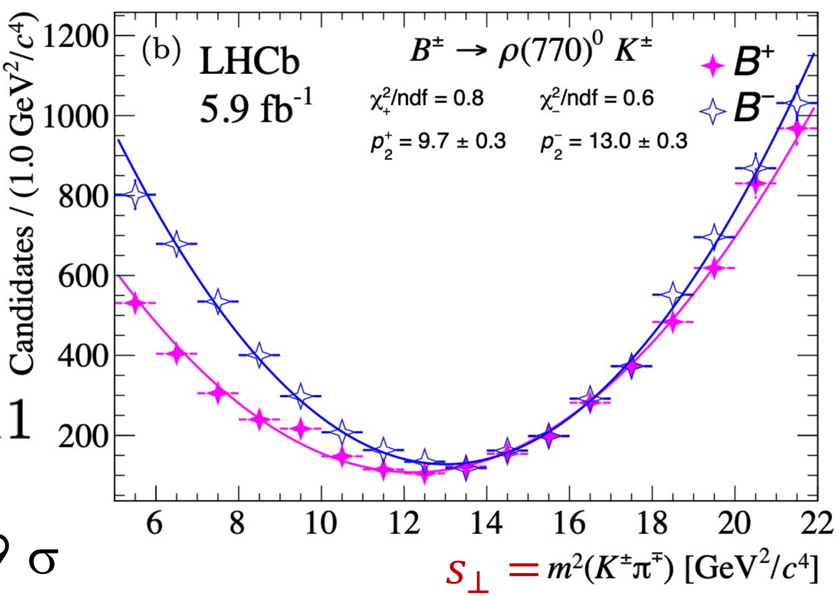
$B^\pm \to R(h_1^- h_2^+) h_3^\pm$ *where R is the resonance*

m_V is the vector mass

$s_\perp$ is $m^2(h_1^- h_3^+)$

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

$$A_{CP}(\rho(770)^0 K^\pm) = +0.150 \pm 0.019 \pm 0.011$$



First CP violation observation at 7.9 σ

CP violation in charm

CP violation was observed in 2019 by LHCb with $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays measuring the difference of the time-integrated CP asymmetry

$$\Delta A_{CP} = A_{CP}(KK) - A_{CP}(\pi\pi)$$

LHCb observed (5.3 σ) CP violation in the neutral charm decay

$$\Delta A_{CP} = (-15.4 \pm 2.9)\times 10^{-4}$$

Time-integratede CP asymmetry

$$A_{CP}(f) = \frac{\int \epsilon(t)[\Gamma(\mathrm{D}^0 \to f)(t) - \Gamma(\bar{\mathrm{D}}^0 \to \bar{f})(t)]\mathrm{d}t}{\int \epsilon(t)[\Gamma(\mathrm{D}^0 \to f)(t) + \Gamma(\bar{\mathrm{D}}^0 \to \bar{f})(t)]\mathrm{d}t} = a_f^d + \frac{<t>_f}{\tau_{D^0}} \Delta Y_f$$

$\epsilon(t)$ is the time-depedent reconstruction efficiency
ΔY_f is related to charm mixing parameters
$< t >_f$ is the average acceptance-dependent decay time of the D^0 mesons in the experimental sample

CP violation in $D^0 \to K^- K^+$

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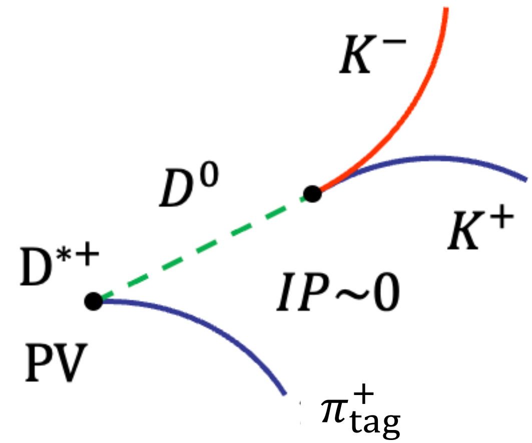
The flavour of the initial state (D^0 or $\bar{D}^0$) is tagged by the charge of the pion from $D^{*+} \to D^0 \pi^+_{\text{tag}}$ and $D^{*-} \to \bar{D}^0 \pi^-_{\text{tag}}$ coming from primary verteces

Prompt D^{*+} decay



The asymmetry, made of the number of reconstructed D^0 and $\bar{D}^0$, is defined as

$$A = \frac{N(D^0 \to f) - N(\bar{D}^0 \to \bar{f})}{N(D^0 \to f) + N(\bar{D}^0 \to \bar{f})}$$

and it is related to the CP asymmetry as

$$A = A_{CP} + \underbrace{A_D(\pi) + A_P(D^{*+})}_{\text{nuisance asymmetries}}$$

production asymmetry

$$A_P = \frac{\sigma(D) - \sigma(\bar{D})}{\sigma(D) + \sigma(\bar{D})}$$

reconstruction asymmetry

$$A_D = \frac{\epsilon(f) - \epsilon(\bar{f})}{\epsilon(f) + \epsilon(\bar{f})}$$

The strategy

The $D^0 \to K^-K^+$ data sample corresponds to 5.9 fb^{-1} of integrated luminosity recorded during RUN-2

Two sets of control samples to cancel nuisance asymmetries

C_{D^+}: already used in RUN-1

$C_{D_s^+}$: new sets of decay modes to improve precision and cross-check

$$C_{D^+}\colon A_{CP}(D^0 \to K^-K^+) = A\left(D^{*+} \to D^0(K^-K^+)\pi^+_{\text{tag}}\right) - A\left(D^{*+} \to D^0(K^-\pi^+)\pi^+_{\text{tag}}\right) + A(D^+ \to K^-\pi^+\pi^+) - A(D^+ \to \overline{K}^0\pi^+) + A(\overline{K}^0)$$

$$C_{D_s^+}\colon A_{CP}(D^0 \to K^-K^+) = A\left(D^{*+} \to D^0(K^-K^+)\pi^+_{\text{tag}}\right) - A\left(D^{*+} \to D^0(K^-\pi^+)\pi^+_{\text{tag}}\right) + A(D_s^+ \to \phi\pi^+) - A(D_s^+ \to \overline{K}^0K^+) + A(\overline{K}^0)$$

A kinematic weighting procedure has been applied to all the data samples

$A(\overline{K}^0)$ is the kaon detection asymmetry including mixing and CPV

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The strategy

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C_{D^+}: already used in RUN-1

$C_{D_s^+}$: new sets of decay modes to improve precision and cross-check

C_{D+}:
$$A_{CP}(D^0 \to K^- K^+) = +A(D^{*+} \to (D^0 \to K^- K^+)\,\pi^+_{soft}) - A(D^{*+} \to (D^0 \to K^- \pi^+)\,\pi^+_{soft}) + A(D^+ \to K^- \pi^+ \pi^+) - \left[A(D^+ \to \overline{K}^0\,\pi^+) - A(\overline{K}^0)\right]$$

C_{Ds+}:
$$A_{CP}(D^0 \to K^- K^+) = +A(D^{*+} \to (D^0 \to K^- K^+)\,\pi^+_{soft}) - A(D^{*+} \to (D^0 \to K^- \pi^+)\,\pi^+_{soft}) + A(D_s^+ \to \phi \pi^+) - \left[A(D_s^+ \to \overline{K}^0\,K^+) - A(\overline{K}^0)\right]$$

Same "color" indicates particles with equalized kinematics

Weigthing procedure

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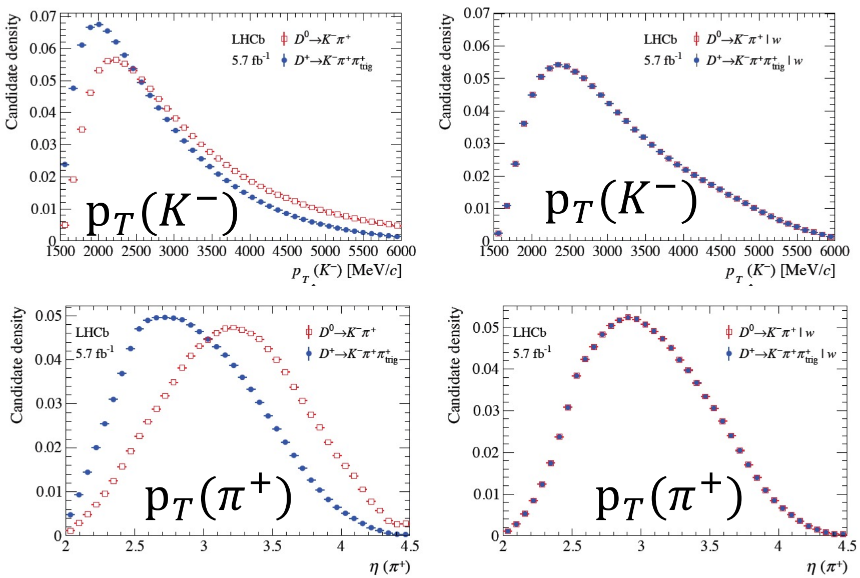
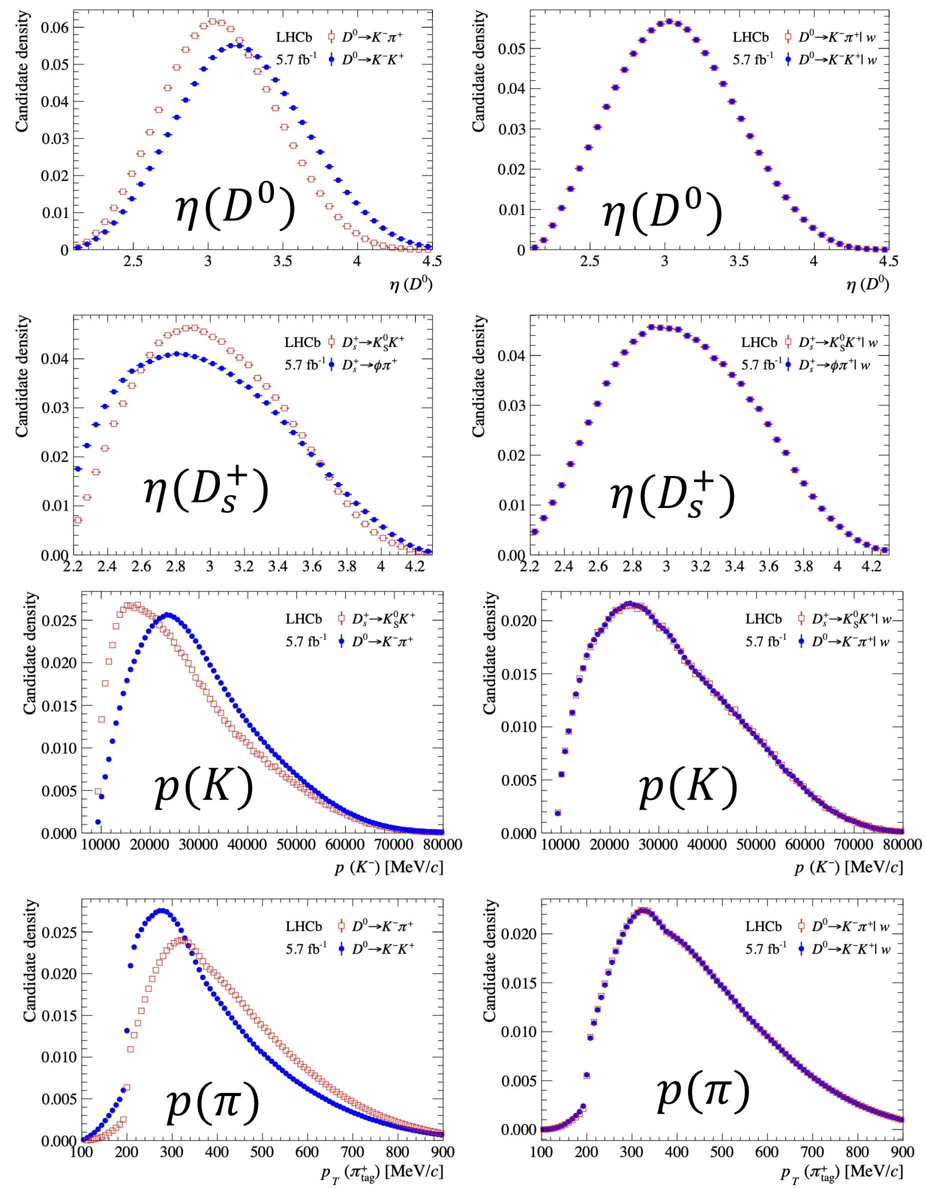
A multi-dimension and iterative algorithm is developed to ensure a good matching between all the particles involved in the various decays

before after



2-body vs 3-body

before after



2-body vs 2-body

Signal yields

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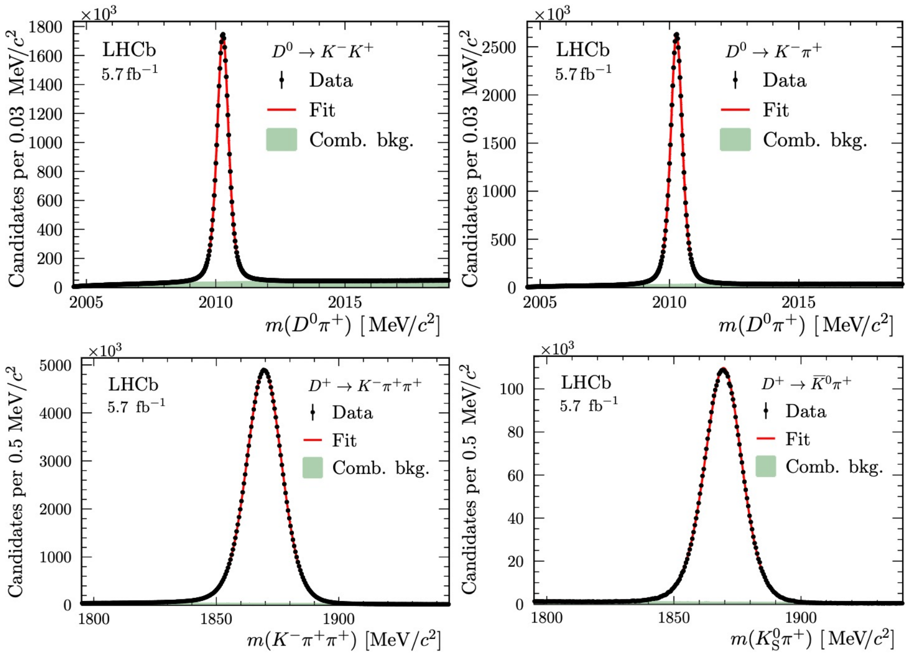
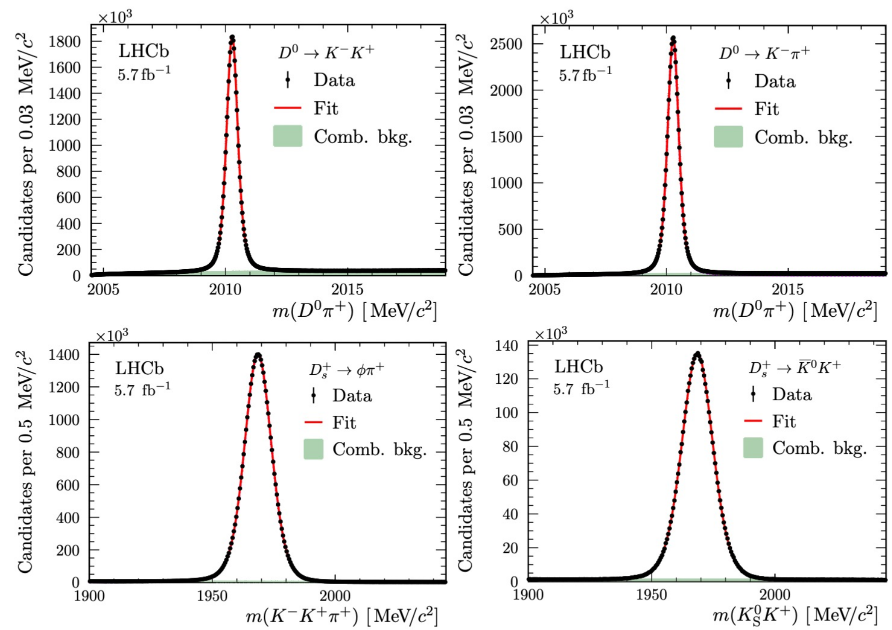


Decay mode	Signal yield [10^6]		Red. factor	
	C_{D^+}	$C_{D_s^+}$	C_{D^+}	$C_{D_s^+}$
$D^0 \to K^-K^+$	37	37	0.72	0.76
$D^0 \to K^-\pi^+$	58	56	0.33	0.76
$D^+ \to K^-\pi^+\pi^+$	188	–	0.23	–
$D^+ \to \bar{K}^0\pi^+$	6	–	0.25	–
$D_s^+ \to \phi\pi^+$	–	43	–	0.55
$D_s^+ \to \bar{K}^0K^+$	–	5	–	0.70

$C_{D_s^+}$ method



C_{D^+} method

Reduction factors correspond to the statistical power of each data sample after the weighting

Large reduction factors are due to the large difference in kinematics among the various decays

Systematic uncertainties

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Source	C_{D^+} $[10^{-4}]$	$C_{D_s^+}$ $[10^{-4}]$	Corr.
Fit model	1.1	1.0	0.05
Peaking backgrounds	0.3	0.4	0.74
Secondary decays	0.6	0.3	–
Kinematic weighting	0.8	0.4	–
Neutral kaon asymmetry	0.6	1.3	1.00
Charged kaon asymmetry	–	1.0	–
Total	1.6	2.0	0.28

Fit model: alternative signal and background fitting models evaluated

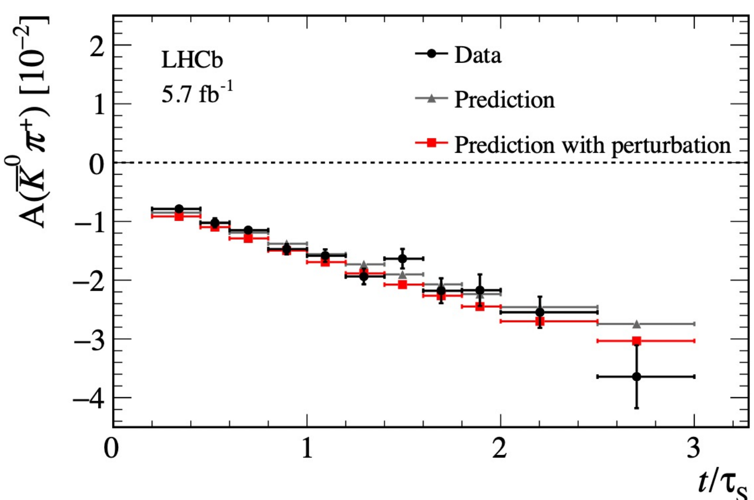
Peaking background: impact estimated by fitting $m(KK)$

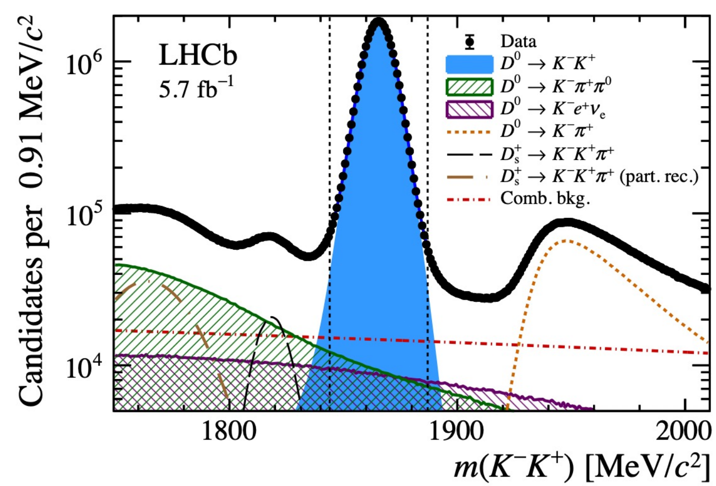
Secondary decays: the presence of D meson from B decays estimated using IP distributions

Kinematic weighting: evaluated the residual difference after the weighing

Neutral kaon asymmetry: accuracy tested with a data-driven approach

Charged kaon asymmetry: K^-K^+ residual asymmetry from $D_s^+ \to \phi\pi^+$





Final results

The value of the CP asymmetries are

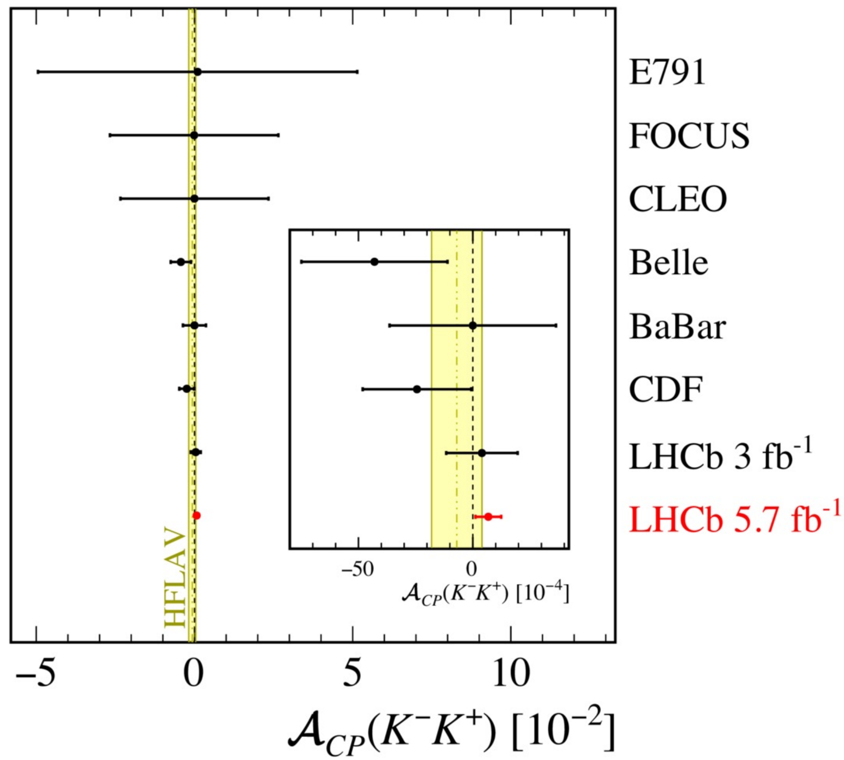
$$C_{D^+}: \ \mathcal{A}_{CP}(K^-K^+) = [13.6 \pm 8.8\,(\text{stat}) \pm 1.6\,(\text{syst})] \times 10^{-4},$$
$$C_{D_s^+}: \ \mathcal{A}_{CP}(K^-K^+) = [\ 2.8 \pm 6.7\,(\text{stat}) \pm 2.0\,(\text{syst})] \times 10^{-4}.$$

with a total correlation corresponding to $\rho = 0.06$

The average corresponds to

$$\mathcal{A}_{CP}(K^-K^+) =$$
$$[6.8 \pm 5.4\,(\text{stat}) \pm 1.6\,(\text{syst})] \times 10^{-4}$$

consistent with the previous results

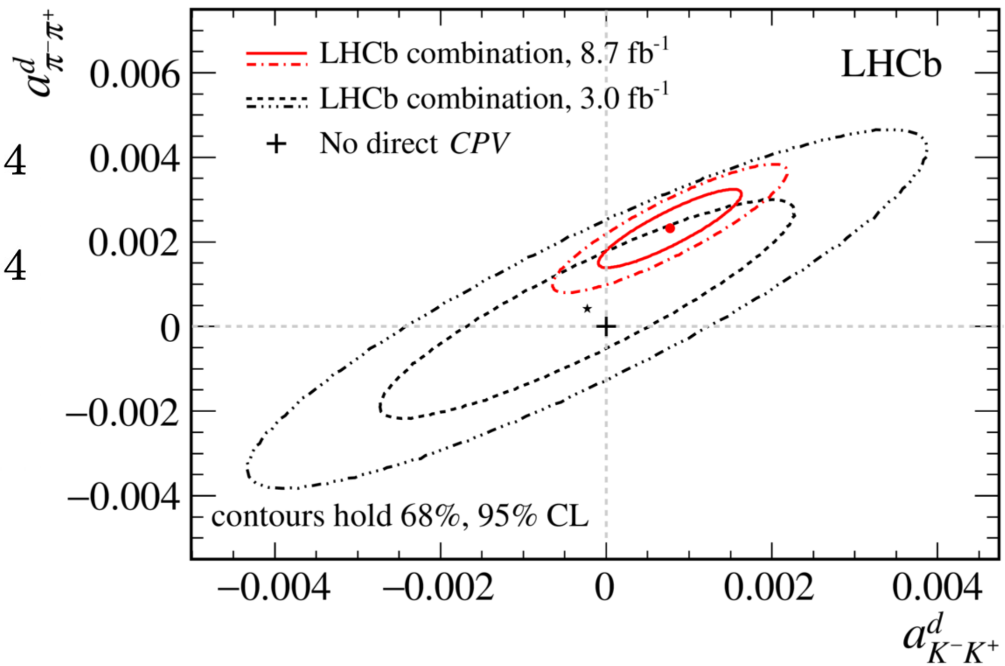


First evidence for direct CP violation

Combining this measurement with the ΔA_{CP} and ΔY_f LHCb measurements

$$a^d_{K^-K^+} = (\ 7.7 \pm 5.7) \times 10^{-4}$$
$$a^d_{\pi^-\pi^+} = (23.2 \pm 6.1) \times 10^{-4}$$

with $\rho(a^d_{KK}, a^d_{\pi\pi}) = 0.88$



This is the first evidence of CP violation (3.8σ) in an individual charm meson decay

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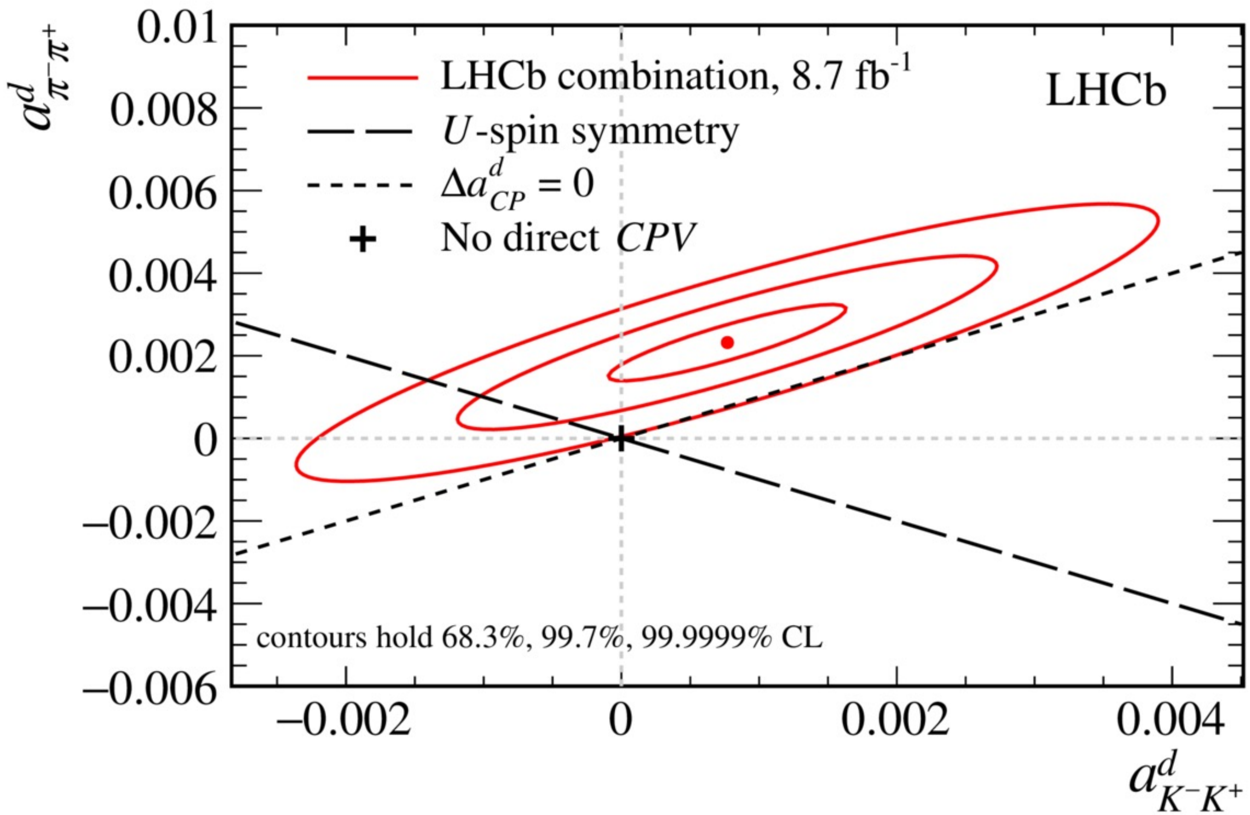
U-spin symmetry



$a_d^{KK} + a_d^{\pi\pi} \neq 0$ at the level of 2.7 standard deviation

LHCb-PAPER-2022-044

γ LHCb combination

LHCb-CONF-2022-003

LHCb-CONF-2022-003

Charm and beaty combination

B decay	D decay	Ref.	Dataset	Status since Ref. [14]
$B^\pm \to Dh^\pm$	$D \to h^+h^-$	[29]	Run 1&2	As before
$B^\pm \to Dh^\pm$	$D \to h^+\pi^-\pi^+\pi^-$	[30]	Run 1	As before
$B^\pm \to Dh^\pm$	$D \to K^\pm\pi^\mp\pi^+\pi^-$	[18]	Run 1&2	**New**
$B^\pm \to Dh^\pm$	$D \to h^+h^-\pi^0$	[19]	Run 1&2	**Updated**
$B^\pm \to Dh^\pm$	$D \to K^0_S h^+h^-$	[31]	Run 1&2	As before
$B^\pm \to Dh^\pm$	$D \to K^0_S K^\pm\pi^\mp$	[32]	Run 1&2	As before
$B^\pm \to D^*h^\pm$	$D \to h^+h^-$	[29]	Run 1&2	As before
$B^\pm \to DK^{*\pm}$	$D \to h^+h^-$	[33]	Run 1&2(*)	As before
$B^\pm \to DK^{*\pm}$	$D \to h^+\pi^-\pi^+\pi^-$	[33]	Run 1&2(*)	As before
$B^\pm \to Dh^\pm\pi^+\pi^-$	$D \to h^+h^-$	[34]	Run 1	As before
$B^0 \to DK^{*0}$	$D \to h^+h^-$	[35]	Run 1&2(*)	As before
$B^0 \to DK^{*0}$	$D \to h^+\pi^-\pi^+\pi^-$	[35]	Run 1&2(*)	As before
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	[36]	Run 1	As before
$B^0 \to D^\mp\pi^\pm$	$D^+ \to K^-\pi^+\pi^+$	[37]	Run 1	As before
$B^0_s \to D^\mp_s K^\pm$	$D^+_s \to h^+h^-\pi^+$	[38]	Run 1	As before
$B^0_s \to D^\mp_s K^\pm\pi^+\pi^-$	$D^+_s \to h^+h^-\pi^+$	[39]	Run 1&2	As before

D decay	Observable(s)	Ref.	Dataset	Status since Ref. [14]
$D^0 \to h^+h^-$	ΔA_{CP}	[24, 40, 41]	Run 1&2	As before
$D^0 \to K^+K^-$	$A_{CP}(K^+K^-)$	[16, 24, 25]	Run 2	**New**
$D^0 \to h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	[42]	Run 1	As before
$D^0 \to h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	[15]	Run 2	**New**
$D^0 \to h^+h^-$	ΔY	[43–46]	Run 1&2	As before
$D^0 \to K^+\pi^-$ (Single Tag)	$R^\pm$, $(x'^\pm)^2$, $y'^\pm$	[47]	Run 1	As before
$D^0 \to K^+\pi^-$ (Double Tag)	$R^\pm$, $(x'^\pm)^2$, $y'^\pm$	[48]	Run 1&2(*)	As before
$D^0 \to K^\pm\pi^\mp\pi^+\pi^-$	$(x^2+y^2)/4$	[49]	Run 1	As before
$D^0 \to K^0_S\pi^+\pi^-$	x, y	[50]	Run 1	As before
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[51]	Run 1	As before
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[52]	Run 2	As before
$D^0 \to K^0_S\pi^+\pi^-$ (μ^- tag)	x_{CP}, y_{CP}, Δx, Δy	[17]	Run 2	**New**

173 observables to determine 52 parameters

Combination based on frequentist approach (also Bayesian analysis performed in the previous combination)

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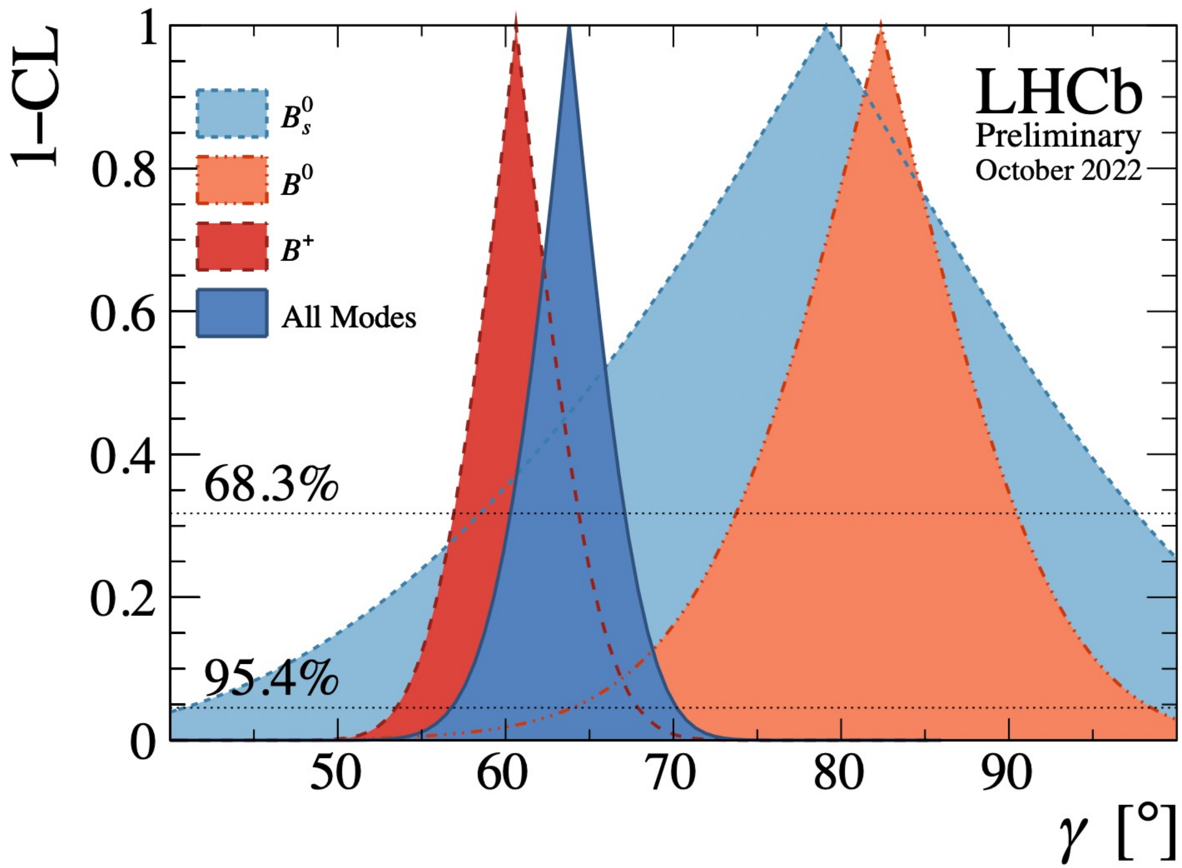
Charm observables also included

Results



LHCb combination

$\gamma = (65.4^{+3.5}_{-3.7})^\circ$

$\gamma_{\text{CKMFitter}} = (65.5^{+1.1}_{-2.7})^\circ$

$\gamma_{\text{UTFit}} = (65.8 \pm 2.2)^\circ$

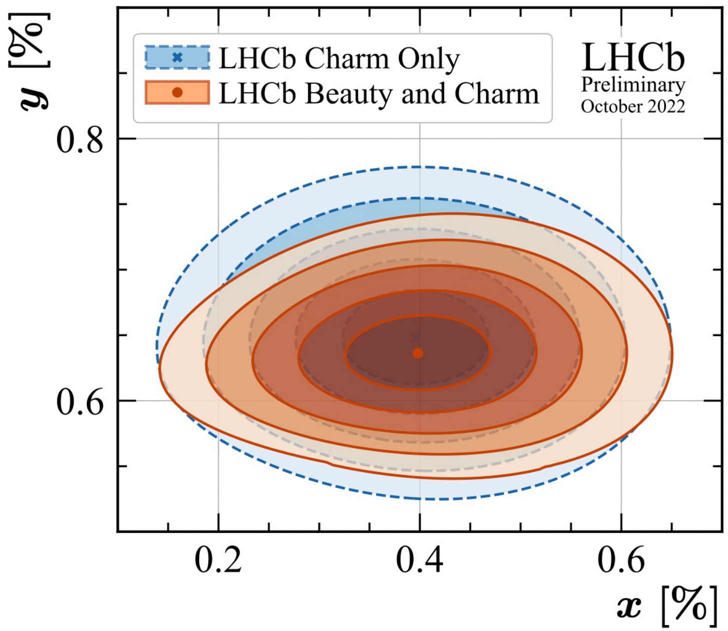
Improvements of about 10% on γ to the previous combination

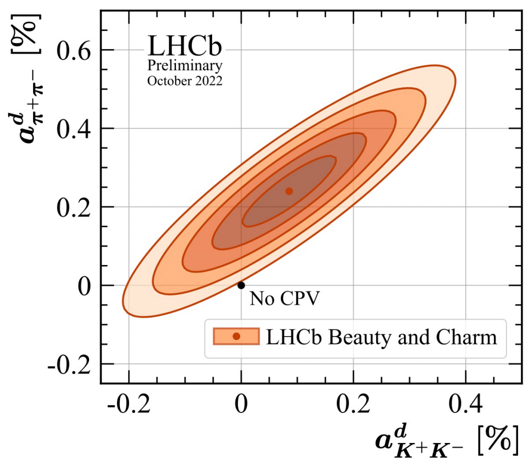
Results

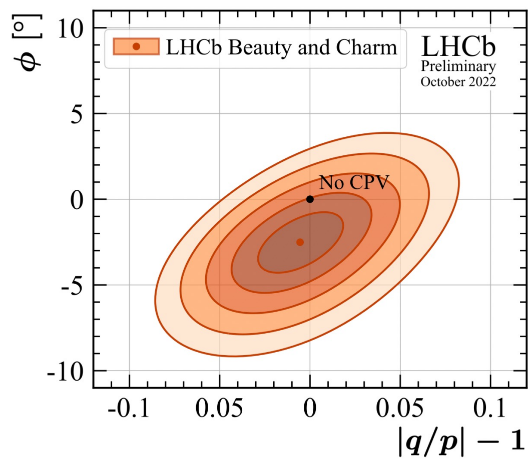
$x = \left(0.398^{+0.050}_{-0.049}\right)\,\%$

$y = \left(0.636^{+0.020}_{-0.019}\right)\,\%$

Improvements of about 6% on x and 38% on y to the previous combination







$\left|\frac{q}{p}\right| = \left(0.995^{+0.015}_{-0.016}\right)$

$\phi = (2.5 \pm 1.5)^\circ$

$a_d^{KK} = (9.0 \pm 5.7)\times 10^{-4}$

$a_d^{\pi\pi} = (24.0 \pm 6.2)\times 10^{-4}$

Evidence for CPV in $a_d^{\pi\pi}$ at 3.6 σ

Conclusions

- The LHCb experiment plays an important role in the determination of CP violation in beauty and charm decays
- Today the latest measurements on CPV in beauty and charm
  - Large CP violation observed in the $B^+ \to hh'h'$ decay and in specific resonances and Dalitz regions
  - First evidence of CP violation in an individual charm decay, $D^0 \to \pi^-\pi^+$
  - Last combination of the CKM parameter γ and charm parameters
- LHCb-Upgrade-I commissioning is proceeding well and important milestones have been achieved so far