Highlights of Recent LHCb Results on Heavy Flavor & CPV

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On behalf of LHCb collaboration

FLASY2019
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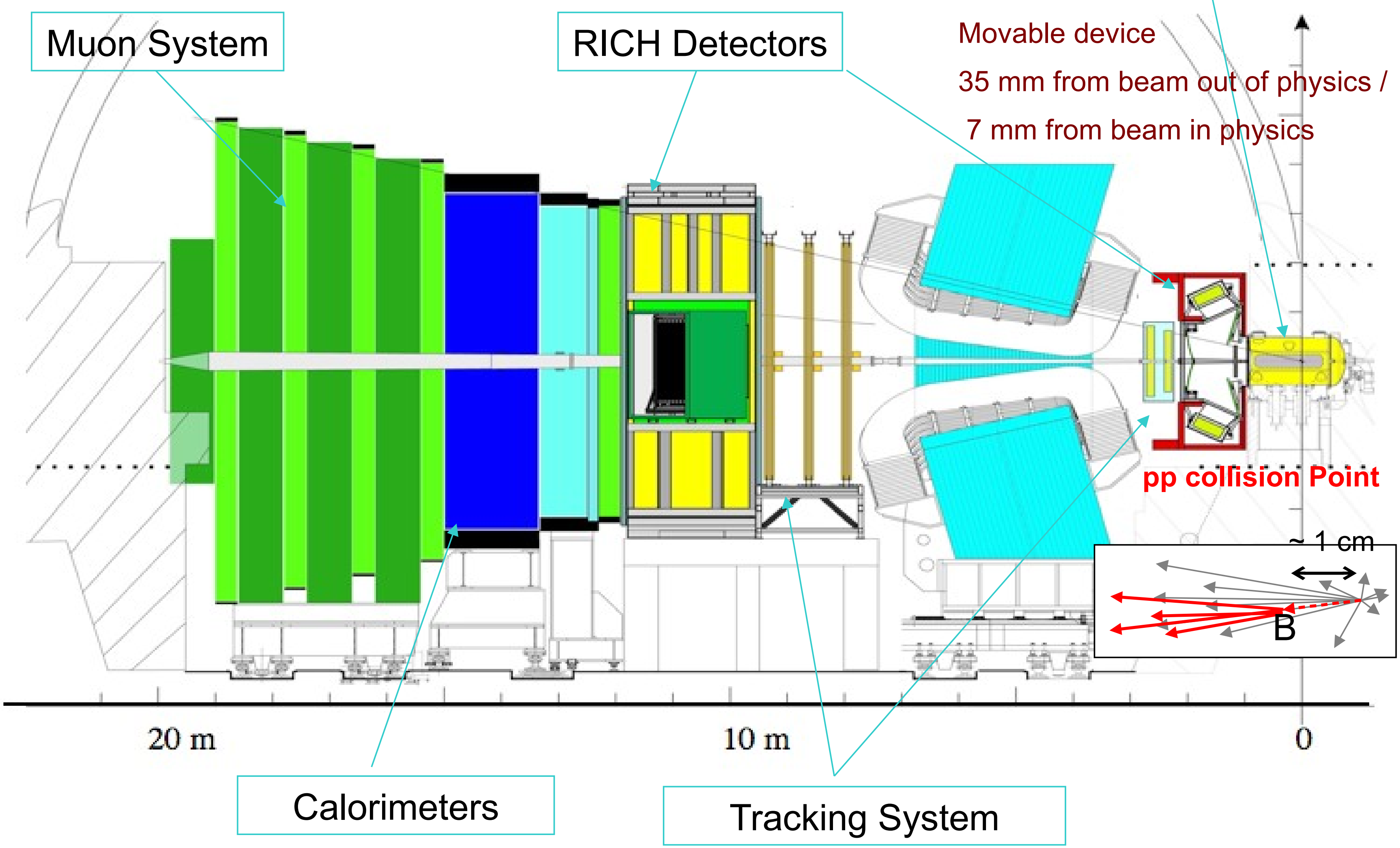
A “biased” selection of recent results

- Lepton Universality tests
  - R(D*) measurement with $\tau \to 3\pi X$ [PRL 120 (2018) 171802, PRD 97 (2018) 072013]
  - R(K) measurement [PRL 122 (2019) 191801]
- (Very) Rare B decays
  - Search for LFV $B_{(s)} \to \tau^{\pm}\mu^{\mp}$ [arXiv:1905.06614]
  - Search for LFV $B^+ \to K^+\mu^{\pm}e^{\mp}$ [LHCB-PAPER-2019-022]
- CPV in B decays
  - Results of γ measurements from $B \to DK^{(*)}$ [LHCb-CONF-2018-002, arXiv:1906.08297]
  - B_s mixing phase ϕ_s from $B_s \to J/\psi$ KK and $B_s \to J/\psi\ \pi\pi$ [arXiv:1903.05530, arXiv:1906.08356]
  - CPV measurement in $B_s \to \phi\phi$ [LHCb-PAPER-2019-019]
- CPV in charm
  - ΔA_{CP} of $D^0 \to KK$, $D^0 \to \pi\pi$ [PRL 122 (2019) 211803]
  - A_Γ in $D^0 \to KK$, $D^0 \to \pi\pi$ [LHCb-CONF-2019-001]
  - Oscillation of charm mesons in $D^0 \to K_s\pi\pi$ [PRL 122 (2019) 231802]
  - Search for CPV in $D^+ \to K_S K^+$, $D_s^+ \to K_s\pi^+$, and $D^+ \to \phi\pi^+$ [PRL 122 (2019) 191803]
- Not included: Radiative decays, spectroscopy, multi-quark states, etc.
- For a complete list, see here

[Int. J. Mod. Phys. A30 (2015)1530022]

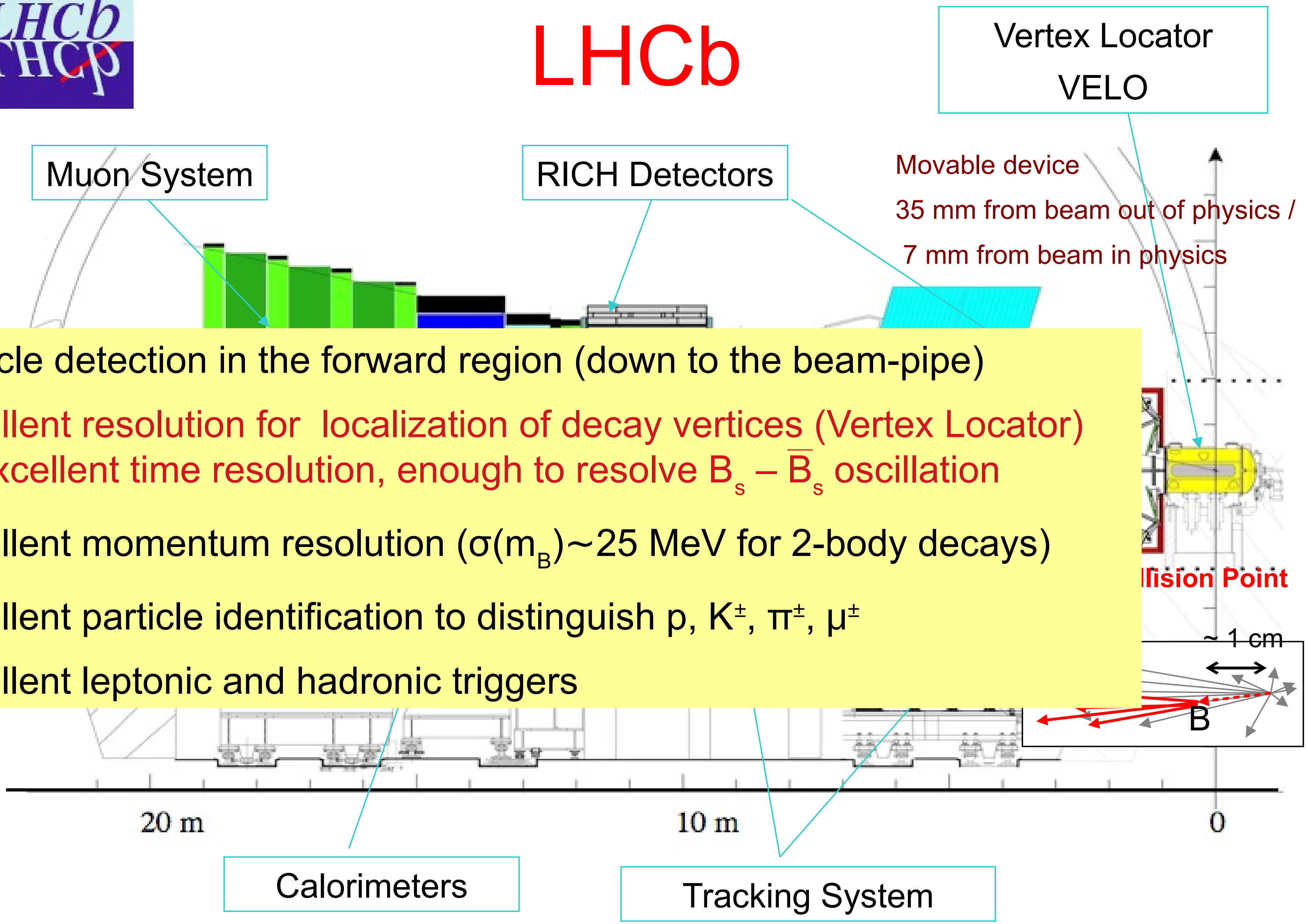
LHCb



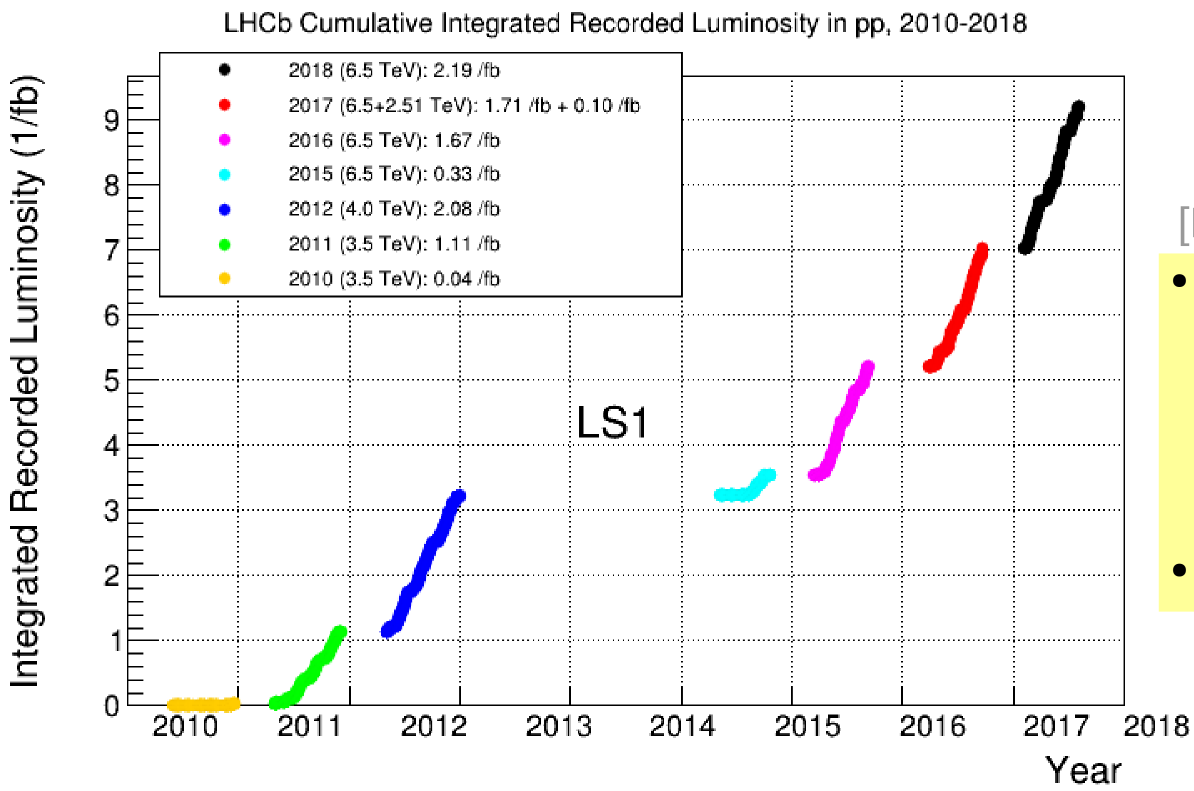
[Int. J. Mod. Phys. A30 (2015)1530022]

LHCb

- Particle detection in the forward region (down to the beam-pipe)
- Excellent resolution for localization of decay vertices (Vertex Locator)
  → Excellent time resolution, enough to resolve $B_s - \bar{B}_s$ oscillation
- Excellent momentum resolution ($\sigma(m_B)$~25 MeV for 2-body decays)
- Excellent particle identification to distinguish p, $K^\pm$, $\pi^\pm$, $\mu^\pm$
- Excellent leptonic and hadronic triggers



LHCb dataset



[PRL 118 (2017) 052002]

- $b\bar{b}$ cross-section @ $\sqrt{s}$ = 13 TeV: 154.3 ± 1.5 ± 14.3 μb
  - ~10^5 $b\bar{b}$ pairs produced/second and all species of b hadrons: $B^{\pm}$, B^0, B_s^0, B_c^+, Λ_b^0,...
- Charm production ~20x higher

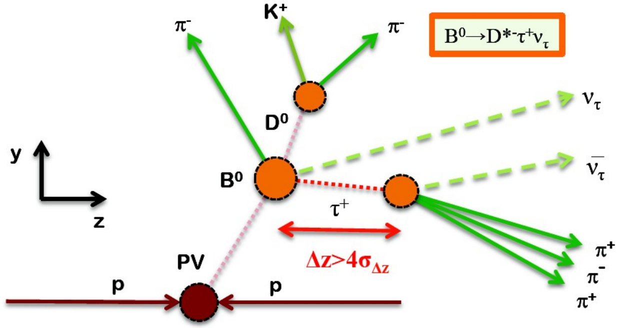
Most of the present analyses use:

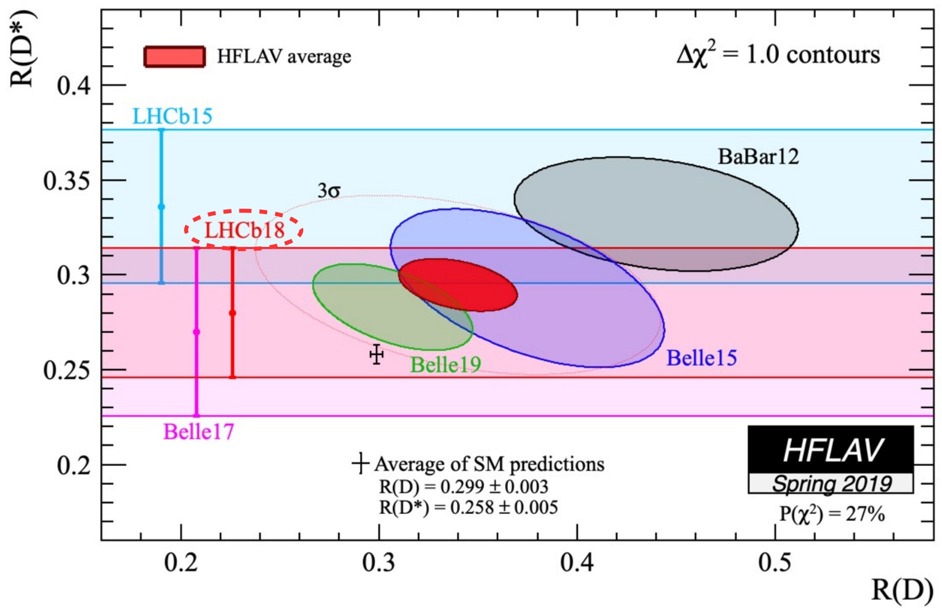
- Run I: 1.0 fb^{-1} @ 7 TeV (2011) + 2.0 fb^{-1} @ 8 TeV (2012)
- Run II: 0.3 fb^{-1} (2015) + 1.7 fb^{-1} (2016) + 1.7 fb^{-1} (2017) + 2.2 fb^{-1} (2018) @ 13 TeV

Lepton universality test: R(D*)

$$\mathcal{R}(D^*) = \frac{\mathcal{B}(\bar{B}^0 \to D^{*+}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B}^0 \to D^{*+}\mu^-\bar{\nu}_\mu)}$$

- τ/μ ratio well predicted in the SM
  - Sensitive to charged Higgs bosons and leptoquarks
- LHCb measurement with Run1 3fb^{-1} data by reconstructing τ through $\tau \to \pi\pi\pi(\pi^0)\nu$
  - Normalized to $\bar{B}^0 \to D^{*+}\pi\pi\pi$
  - Major backgrounds $B^0 \to D^{*+}D_{(s)}^+$ with $D_{(s)}^+ \to \pi\pi\pi X$, can be better understood with BESIII data
- Ongoing work with full Run2 6 fb^{-1} data





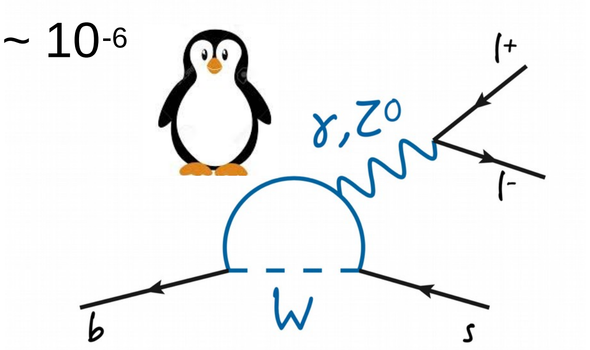
R(D$^{(*)}$) still 3σ from SM after inclusion of new results from Belle @ Moriond EW 2019

Lepton universality test: R(K)

- FCNC b→sll processes highly suppressed at loop level → BR ~ 10^{-6}
- SM predicts R(K) to be very close to one:

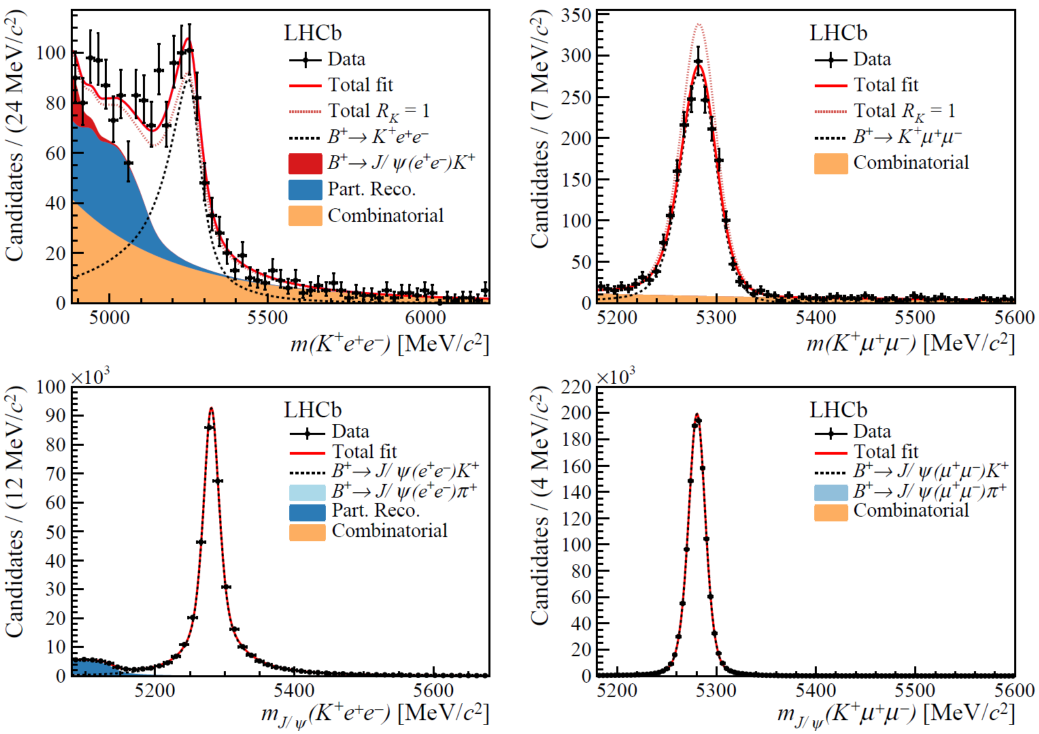
$$R(K^{(*)}) = \frac{BR(B \to K^{(*)} \mu\mu)}{BR(B \to K^{(*)} ee)} = 1 \pm \underbrace{O(10^{-3})}_{\text{neglect lepton mass}} \pm \underbrace{O(10^{-2})}_{\text{QED}}$$

[EPJ C76 (2016) 8, 440]



- Previous LHCb R(K) result based on Run1 $3fb^{-1}$ was different from one with 2.6σ significance [PRL 113 (2014) 151601]
- New measurement adds 2 fb^{-1} Run2 data
  - Double ratio to cancel systematic uncertainties

$$R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))} \Bigg/ \frac{\mathcal{B}(B^+ \to K^+e^+e^-)}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))}$$



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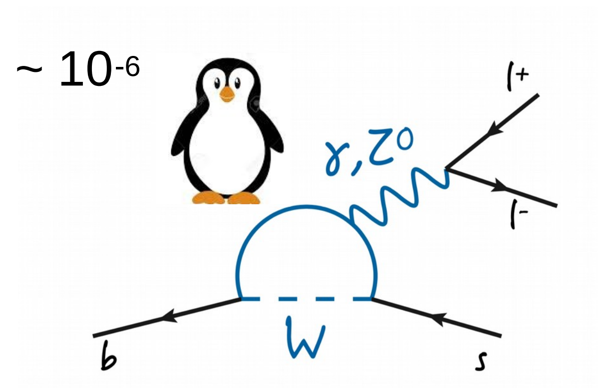

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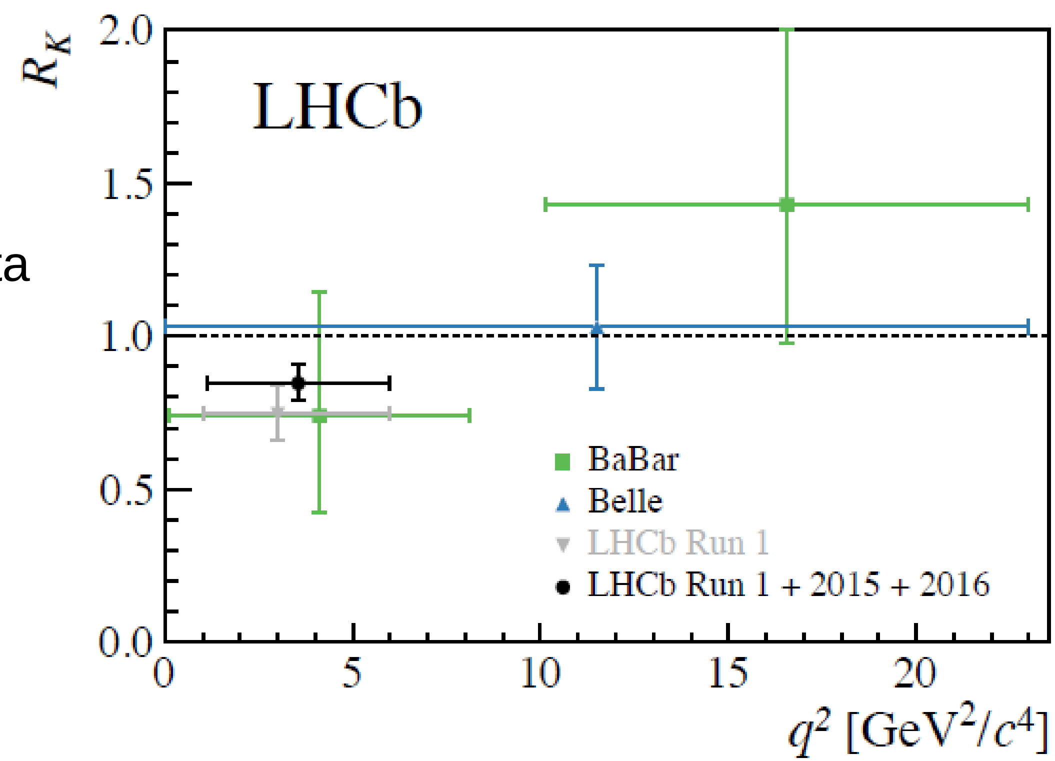
1.1 GeV < q^2 < 6 GeV

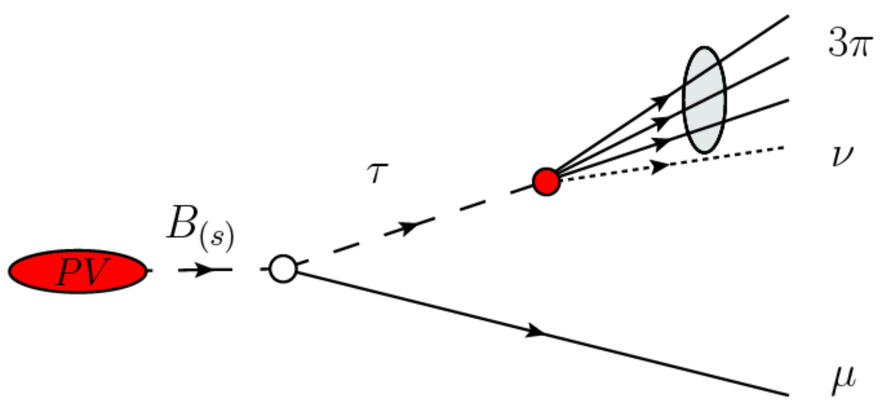
$$R_K = 0.846\ ^{+0.060}_{-0.054}(\text{stat.})\ ^{+0.016}_{-0.014}(\text{syst.})$$

→ Still consistent, lower, than the SM at **2.5σ**



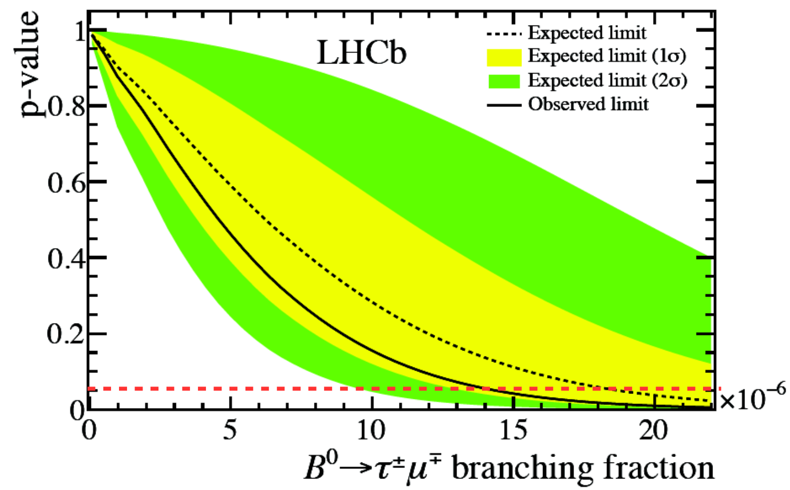
Search for LFV $B^0_{(s)} \to \tau\mu$

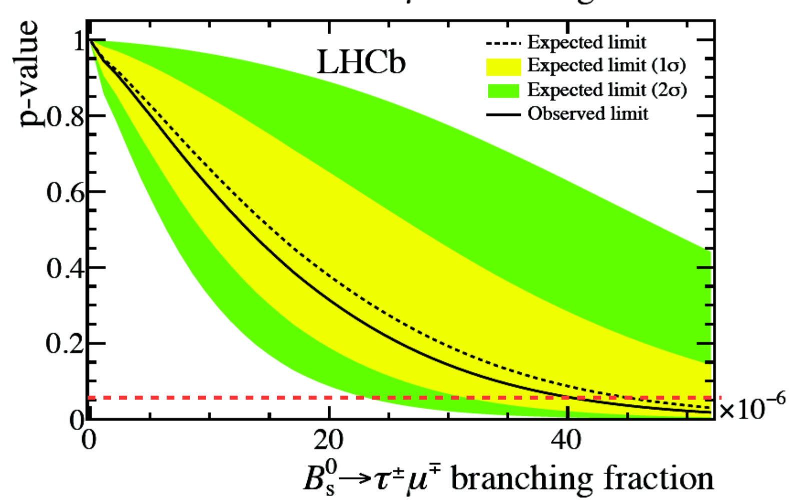
- BR in SM highly suppressed: $\sim 10^{-54}$ [arXiv:1709.00294]
  - Beyond the reach of current experiments
- Recent hints of deviation from LU in B decays (R(K(*)), R(D(*)), …) strongly motivate searches for LFV decays
  - Some NP models foresee BR enhancement to levels accessible at LHC
- LHCb measurement with Run1 3fb^{-1} data
  - Reconstruction of τ: three prong
  - Normalization channel with similar topology: $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$
  - Same-sign data employed to model background



- No presence of signal, limits are set at 95% CL

$$\mathcal{B}\left(B^0 \to \tau^\pm\mu^\mp\right) < 1.4 \times 10^{-5}$$
$$\mathcal{B}\left(B^0_s \to \tau^\pm\mu^\mp\right) < 4.2 \times 10^{-5}$$





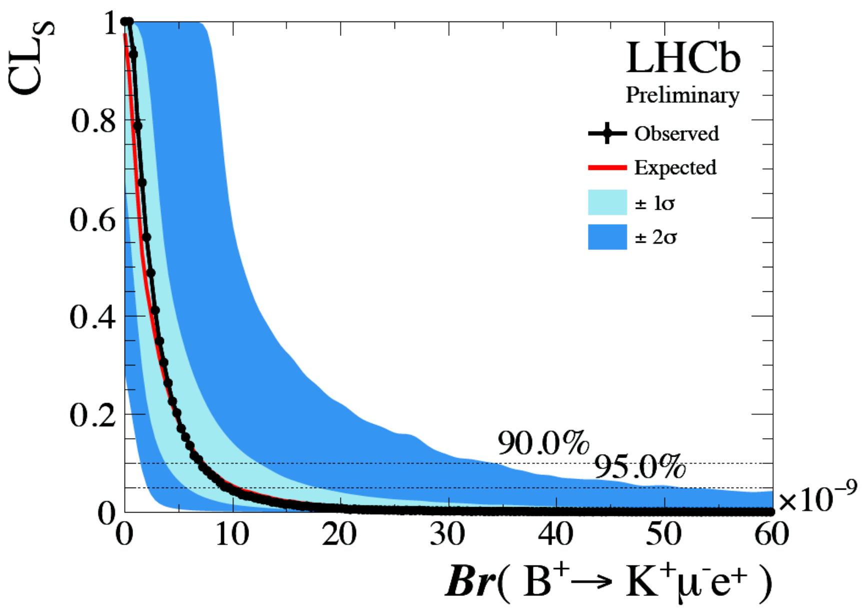
Search for LFV $B^+ \to K^+ e^\mp \mu^\pm$

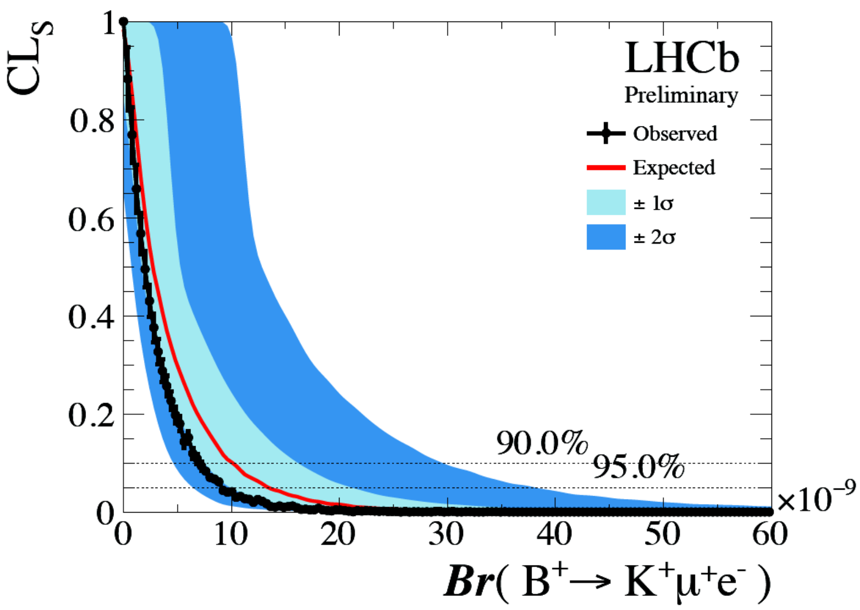
- LHCb measurement with Run1 3fb^{-1} data
  - Normalization channel with similar topology: $B^+ \to J/\psi(\mu^+\mu^-)K^+$
  - Sideband data employed to model background
- No presence of signal: limits on BRs are set:

$\mathcal{B}/10^{-9}$	90% C. L.	95% C. L.
$B^+ \to K^+\mu^-e^+$	7.0	9.5
$B^+ \to K^+\mu^+e^-$	7.1	9.1

LHCb preliminary

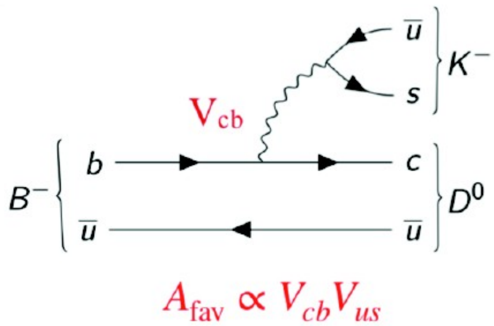
  - Limits improved by more than one order of magnitude

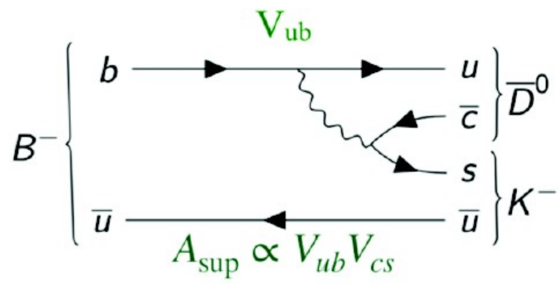


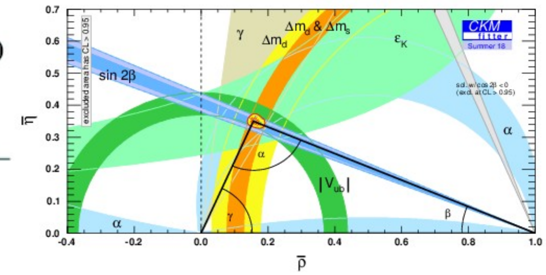


Measuring CKM angle γ

- Can be measured using exclusively tree-level decays such as B → Dh (h = K, K*, π, ππ)
  - Interference between b→c (favored) and b→u (suppressed) transitions







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

$$\frac{A_{sup}}{A_{fav}} = r_B^{Dh} e^{\delta_B^{Dh} \pm \gamma}$$

where **r** is the ratio of magnitudes and **δ** the strong phase difference

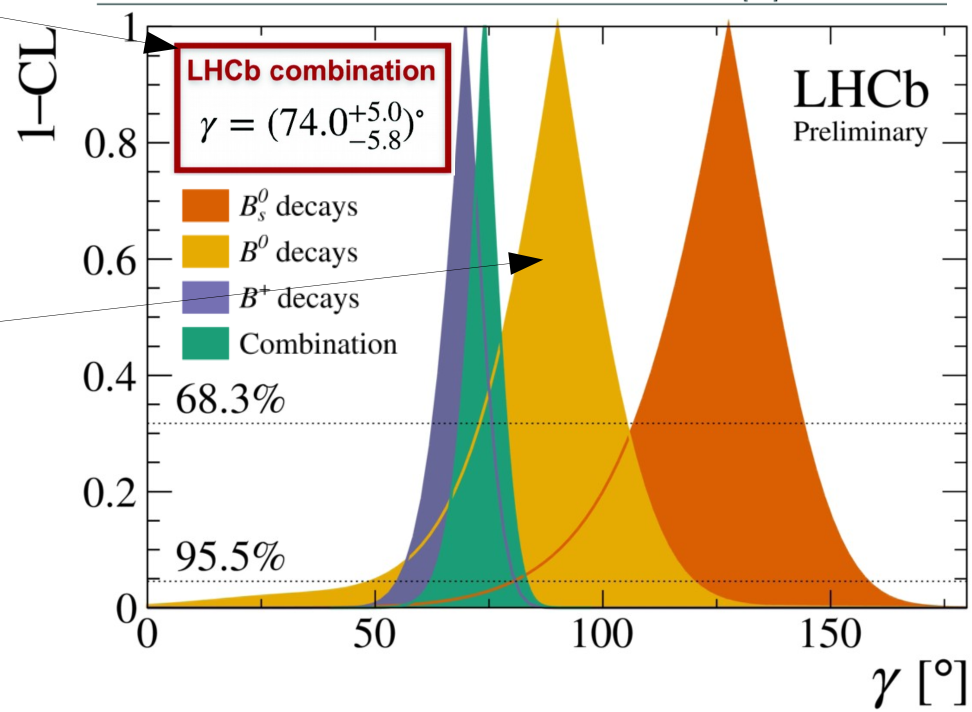
- Can be obtained via time-dependent or time-integrated methods (GLW, ADS, …)
  - Best precision achieved by combing measurements from many decay modes

LHCb γ combination

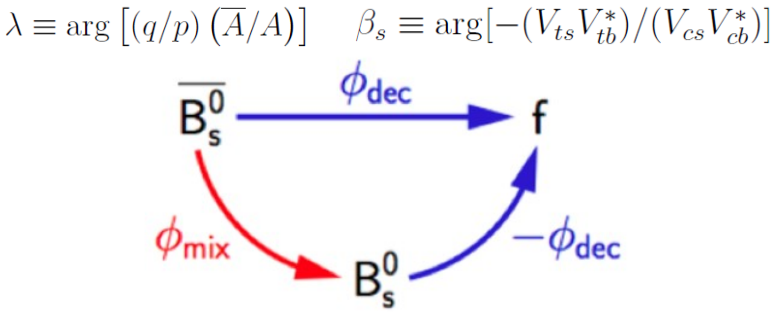
- Combing many tree-level determinations of γ
  - New and updated results using Run 2 2 fb^{-1} data
  - Analyses with full Run 2 6 fb^{-1} data yet to come
- The γ world average is currently dominated by the 2018 LHCb combination
  - LHCb combination is dominated by B^+ decays
- New inputs from the ADS/GLW analysis of $B^0 \to DK^{*0}$ ($D \to KK$, $K\pi$, $\pi\pi$, $K\pi\pi\pi$, $\pi\pi\pi\pi$) [arXiv:1906.08297] to be added to the combination
  - Reduction in the yellow region!

Direct BESIII measurements on strong phase parameters in D decays are important for LHCb γ measurements

B decay	D decay	Method	Ref.	Dataset†
$B^+ \to DK^+$	$D \to h^+h^-$	GLW	[14]	Run 1 & 2
$B^+ \to DK^+$	$D \to h^+h^-$	ADS	[15]	Run 1
$B^+ \to DK^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[15]	Run 1
$B^+ \to DK^+$	$D \to h^+h^-\pi^0$	GLW/ADS	[16]	Run 1
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ	[17]	Run 1
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ	[18]	Run 2
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS	[19]	Run 1
$B^+ \to D^*K^+$	$D \to h^+h^-$	GLW	[14]	Run 1 & 2
$B^+ \to DK^{*+}$	$D \to h^+h^-$	GLW/ADS	[20]	Run 1 & 2
$B^+ \to DK^{*+}$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[20]	Run 1 & 2
$B^+ \to DK^+\pi^+\pi^-$	$D \to h^+h^-$	GLW/ADS	[21]	Run 1
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS	[22]	Run 1
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz	[23]	Run 1
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ	[24]	Run 1
$B^0_s \to D_s^{\mp}K^{\pm}$	$D_s^+ \to h^+h^-\pi^+$	TD	[25]	Run 1
$B^0 \to D^{\mp}\pi^{\pm}$	$D^+ \to K^+\pi^-\pi^+$	TD	[26]	Run 1



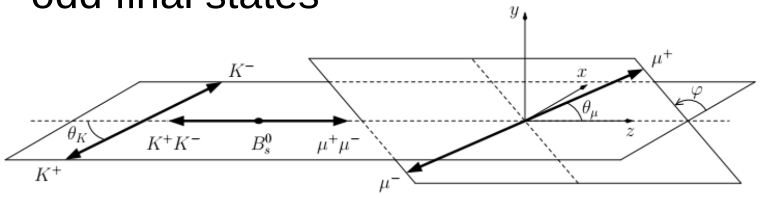
B_s mixing phase ϕ_s



- Mixing-induced CPV phase in $b \to c\bar{c}s$ processes

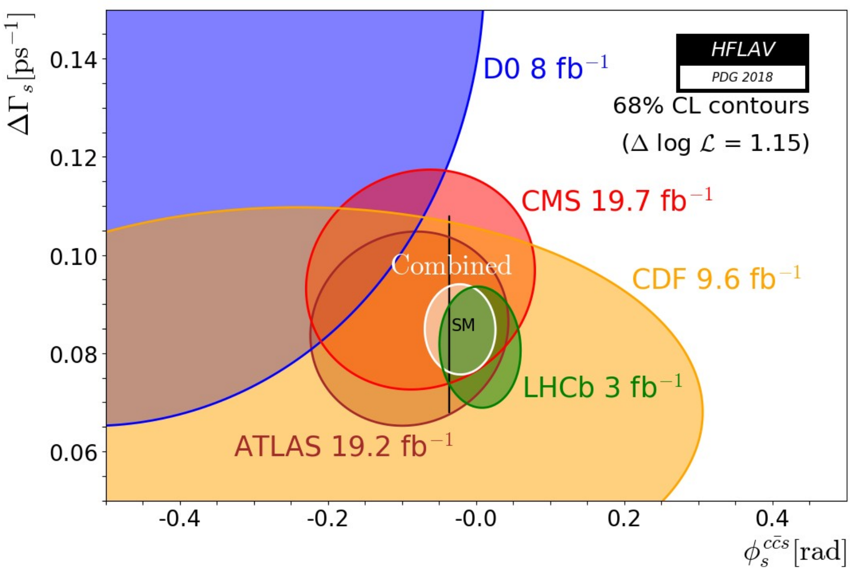
$$\phi_s = -\arg(\lambda) = \phi_{mix} - 2\,\phi_{dec} \approx -2\beta_s$$

  - Well predicted in SM, NP could bring in sizable contribution
- Accessed through LHCb measurement of time-dependent CP asymmetries in B_s decays to CP eigenstates e.g. $B_s \to J/\psi\phi$ with
  - Good decay time resolution (fast B_s oscillation)
  - Efficient flavor tagging power ~5%
  - Angular analysis to disentangle CP-even and CP-odd final states



- World average, then dominated by LHCb Run 1 results, compatible with SM

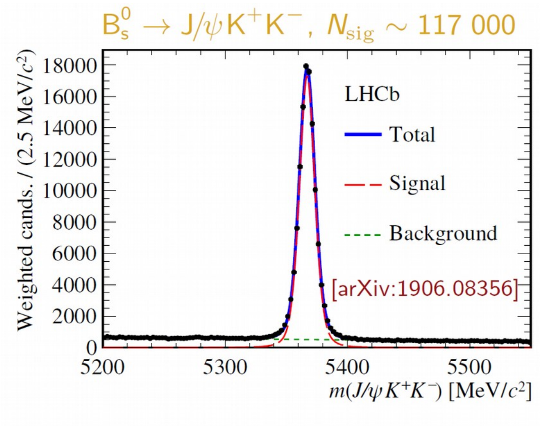
Status of ϕ_s before Moriond EW 2019

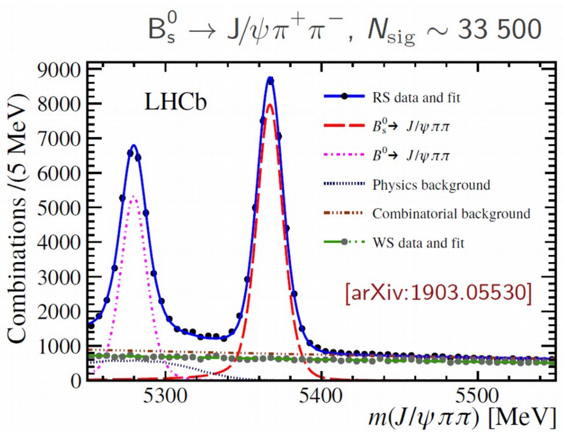


[arXiv:1906.08356, arXiv:1903.05530]

Measurements of ϕ_s with $B_s \to J/\psi hh$

- Update with 2 fb^{-1} Run2 data using $B_s \to J/\psi KK$ [arXiv:1906.08356] and $B_s \to J/\psi\pi\pi$ decays [arXiv:1903.05530]





- Combination of Run1 and Run2 gives the most precise ϕ_s result to date, from a single experiment

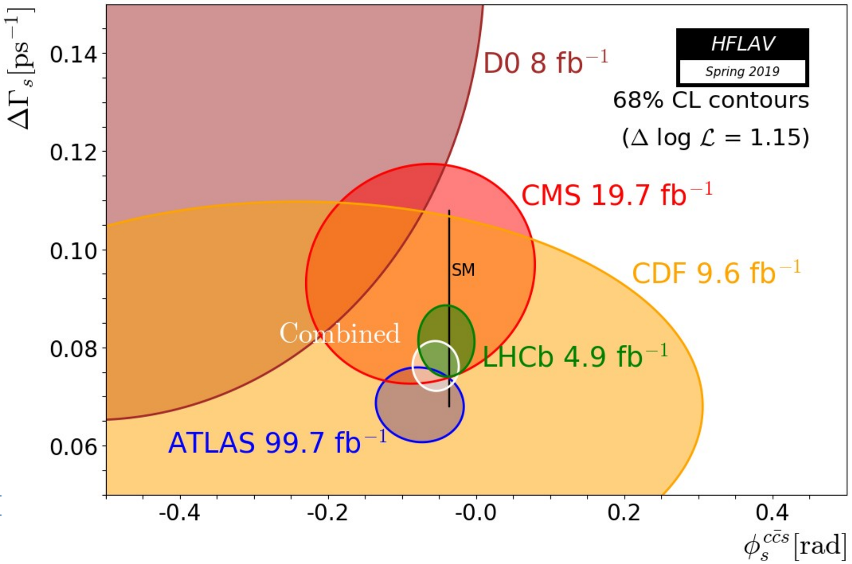
arXiv:1906.08356

$$\phi_s = -0.041 \pm 0.025\,\mathrm{rad}$$
$$\Delta\Gamma_s = 0.0816 \pm 0.0048\,\mathrm{ps}^{-1}$$

Compatible with SM

$$\Delta\Gamma_s \equiv \Gamma_L - \Gamma_H$$

Current status of ϕ_s



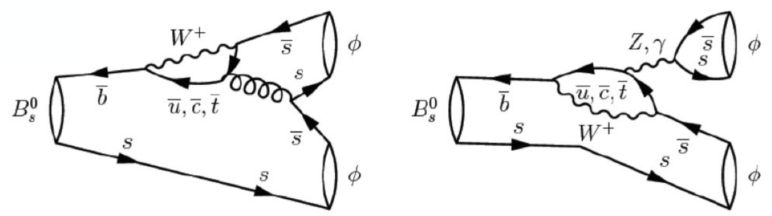
Measurement of CPV in $B \to \phi\phi$

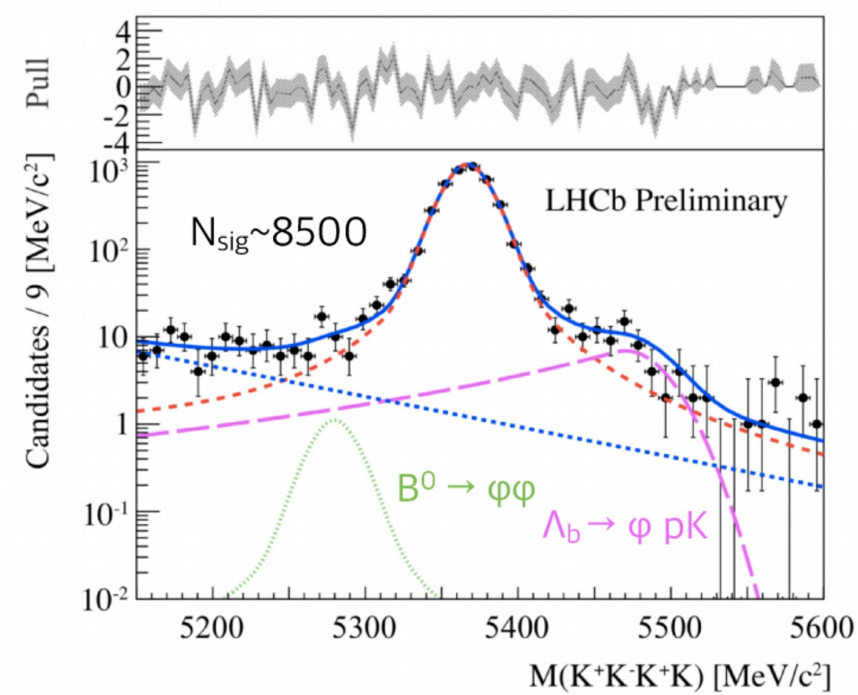
- Enhanced sensitivity to NP since this charmless decay is dominated by $b \to s\bar{s}s$ penguin loop
- Mixing with B_s osculations could give rise to time-dependent CPV
  - CPV phase $\phi_s^{s\bar{s}s}$ predicted < 0.02 rad

    [PRD 80 (2009) 114026]
- Time-dependent angular analysis to disentangle CP eigenstates SS, SV, VV with Run1 + Run2 (2 fb^{-1}) data

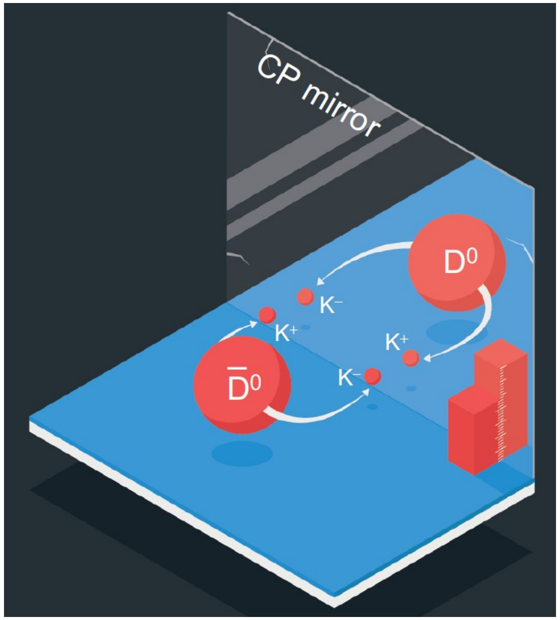
$$\begin{aligned} \phi_s^{s\bar{s}s} &= -0.073 \pm 0.115\,(\text{stat}) \pm 0.027\,(\text{syst})\ \text{rad}, \\ |\lambda| &= 0.99 \pm 0.05\,(\text{stat}) \pm 0.01\,(\text{syst}). \end{aligned}$$

LHCb preliminary





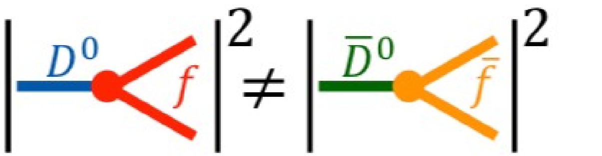
CP violation in charm

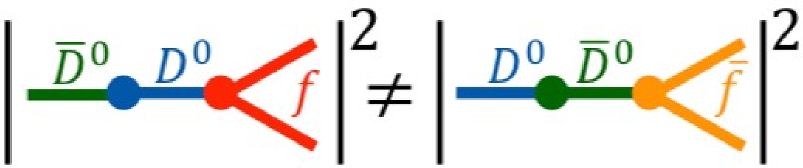


- Charm decays allow CP violation to be probed in the up-sector
  - Complementary to studies in neutral K and $B_{(s)}$ systems
- Expected to be very small in SM (~10^{-3} – 10^{-4})
  - Although theory predictions are not very precise due to large long-distance effects
- CP asymmetries $A_{CP} = \dfrac{\Gamma(D^0 \to f) - \Gamma(\overline{D^0} \to \bar{f})}{\Gamma(D^0 \to f) + \Gamma(\overline{D^0} \to \bar{f})}$

  are sensitive to
  - Direct CP violation a_{CP}^{dir}
  - Indirect CP violation a_{CP}^{ind}

    (CP violation in mixing or in the interference between mixing and decay)





[PRL 122 (2019) 211803]

ΔA_{CP} measurement

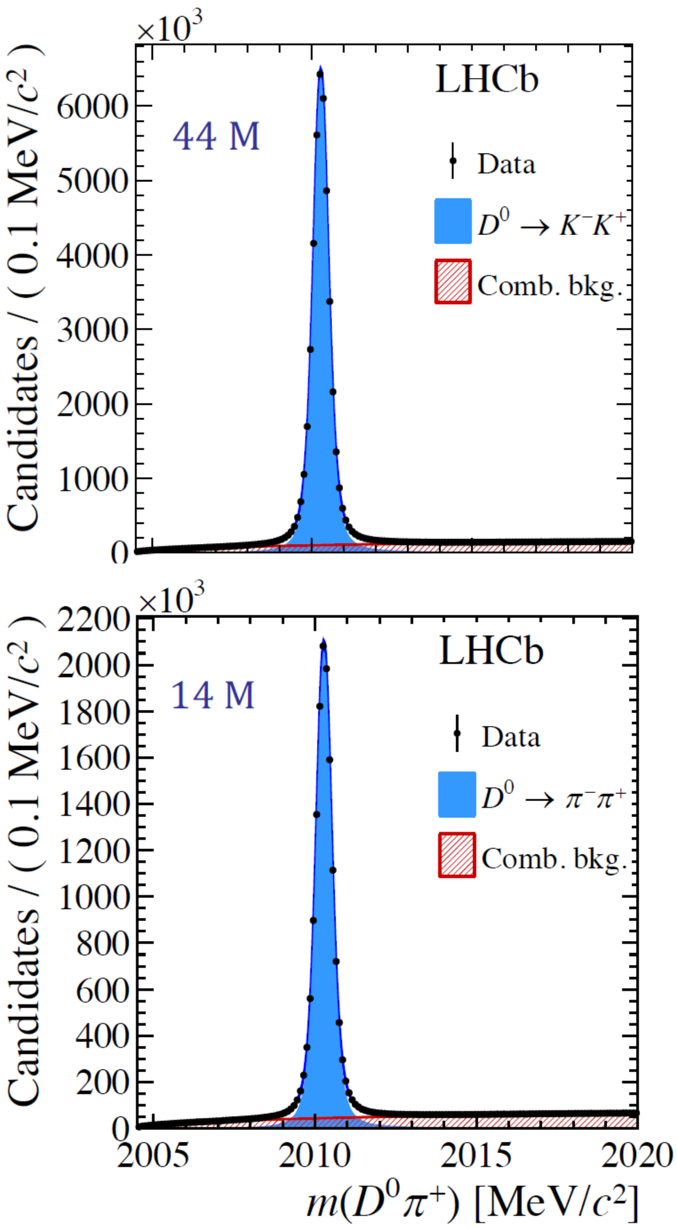
- LHCb uses full Run2 5.9 fb^{-1} data
- Tagging of initial flavor of D^0
  - **Prompt**: coming from PV, i.e., $D^{*+} \to D^0\pi^+$
  - **Semileptonic**: coming from B decays, i.e., $B \to D^0\mu^- X$
- Raw asymmetry for tagged D^0 decays to a final state f (K^+K^-, $\pi^+\pi^-$):

$$A_{\rm raw}(f) = \frac{N(D^0 \to f) - N(\overline{D}^0 \to f)}{N(D^0 \to f) + N(\overline{D}^0 \to f)}$$

- With many systematics canceled at first order, it is relatively easy to measure time-integrated difference in CP asymmetry

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

Prompt D^0



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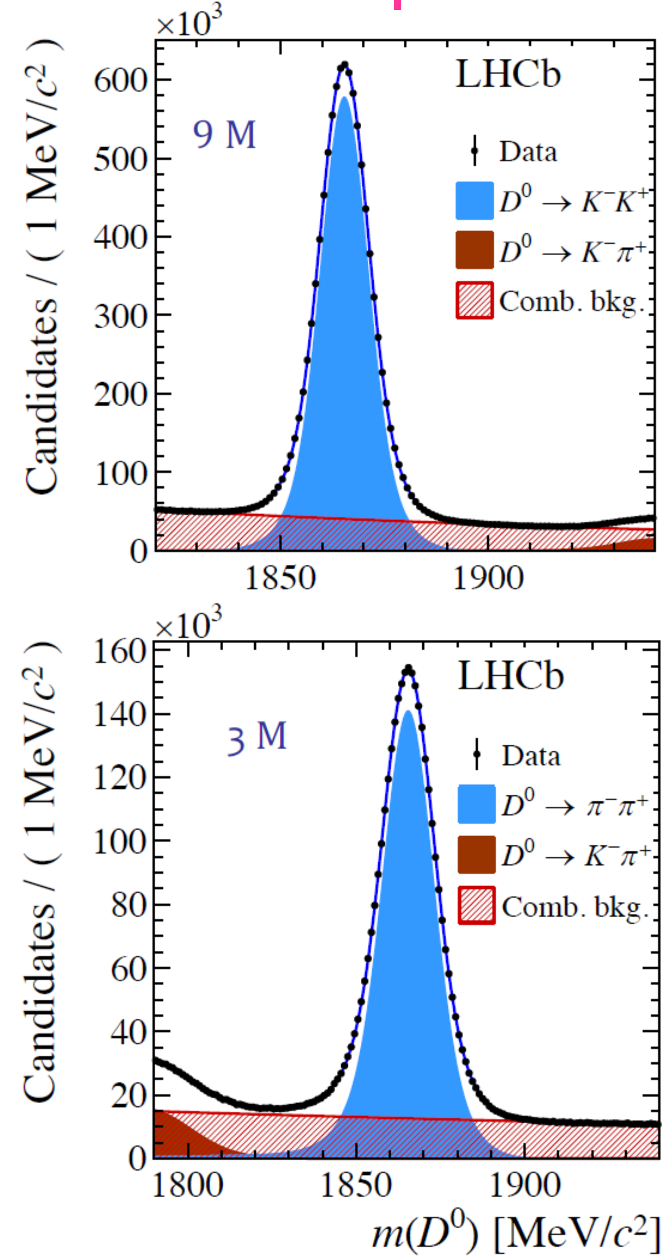
Semileptonic D^0



[PRL 122 (2019) 211803]

Observation of charm CPV

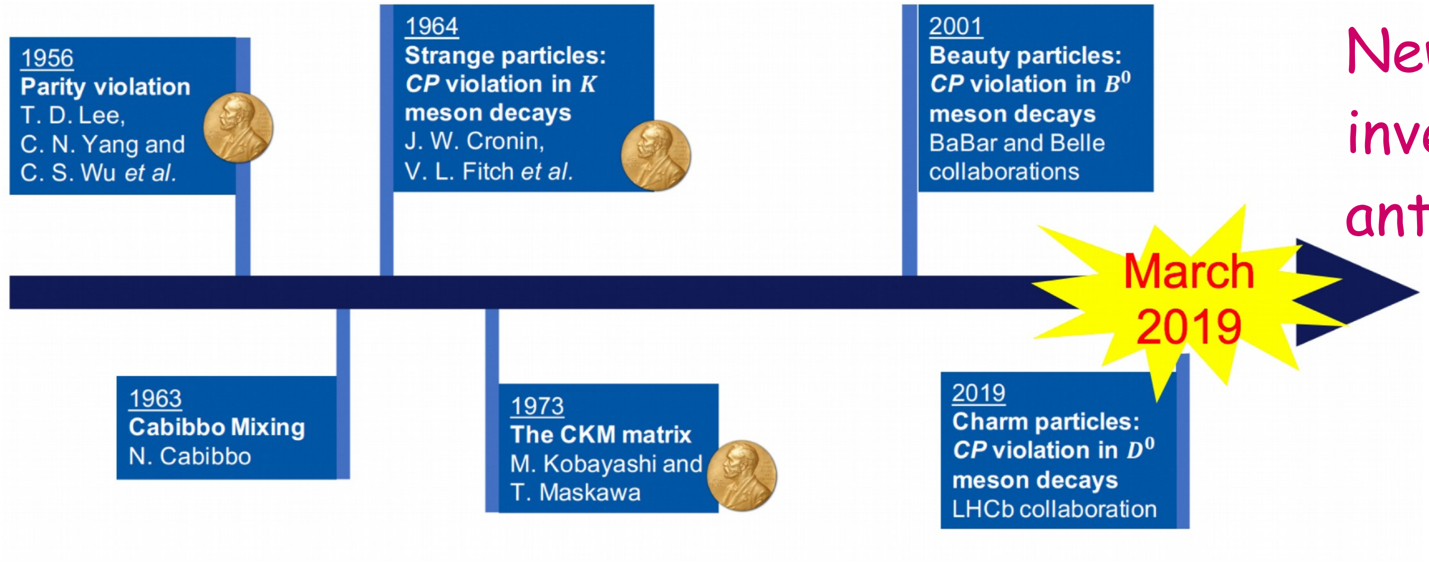
- From full Run2 5.9 fb^{-1} data:

$$\Delta A_{CP}^{\pi-tag} = (-18.2 \pm 3.2 \pm 0.9) \times 10^{-4},$$
$$\Delta A_{CP}^{\mu-tag} = (-9 \pm 8 \pm 5) \times 10^{-4}$$

- Combination with Run1 results:

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

  - Observation of CP violation with **5.3σ** significance!

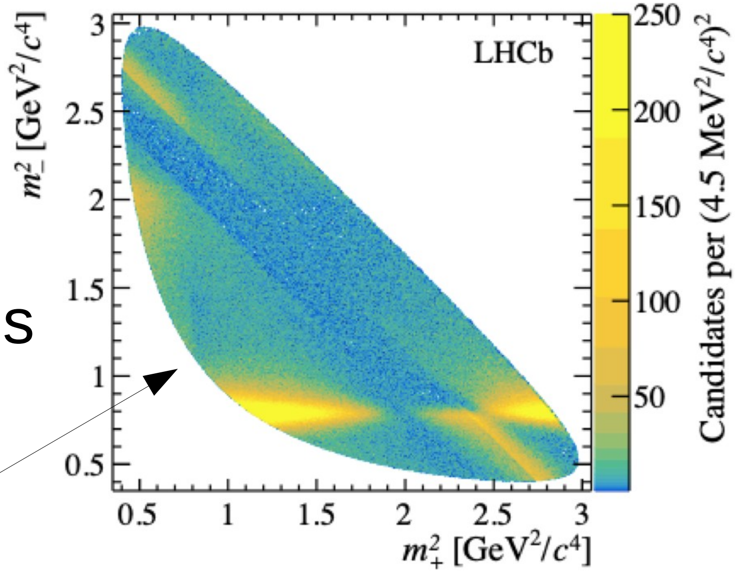


New window opened to investigate matter-antimatter symmetry!

[PRL 122 (2019) 231802]

Oscillations of charm mesons in $D^0 \rightarrow K_S^0 \pi\pi$

- D^0 mass eigenstates and their weak eigenstates:
  - $|\mathbf{D_{1,2}}\rangle = \mathbf{p}\,|\mathbf{D^0}\rangle \pm \mathbf{q}\,|\overline{\mathbf{D^0}}\rangle$
  - $m_{1,2}$ ($\Gamma_{1,2}$) as mass (width) of $D_{1,2}$
- Mixing parameters: $\mathbf{x \equiv \frac{m_1 - m_2}{\Gamma}; y \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}}$
- x determines the oscillation rate
  - x is very small for D^0, but x and CPV can be enhanced by NP
  - CPV can occur in the mixing → oscillation rates differ for D^0 and $\overline{D}^0$
- LHCb Run1, tagged $D^0 \rightarrow K_S^0 \pi\pi$ decay yields
  - Prompt: ~1.3M, Semileptonic: ~1M
- $D^0 \rightarrow K_S^0 \pi\pi$ has rich resonance structures



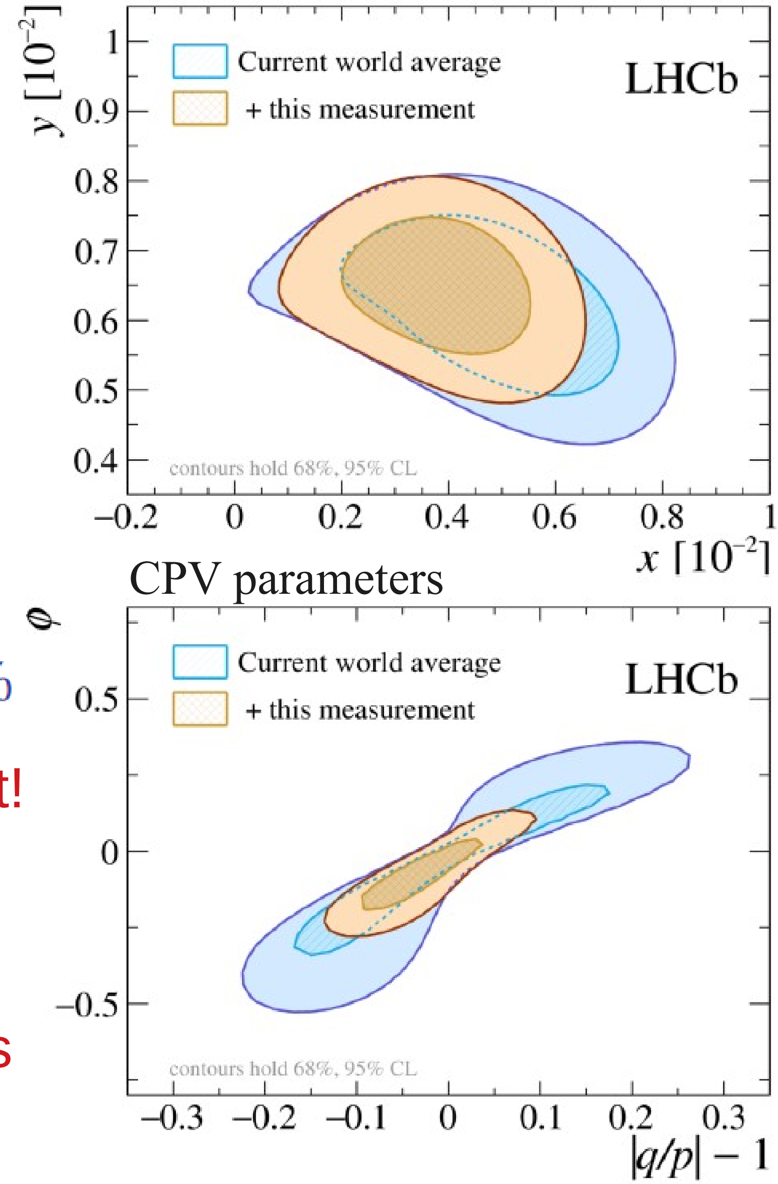
[PRL 122 (2019) 231802]

Oscillations of charm mesons in $D^0 \rightarrow K_S^0 \pi\pi$

- Model-independent approach (bin-flip method) [PRD 99 (2019) 012007]
  - To avoid efficiency modeling
- Results with Run1 data:

$$y_{CP} = [0.74 \pm 0.36\,(stat) \pm 0.11\,(syst)]\%$$
$$\Delta y = [-0.06 \pm 0.16\,(stat) \pm 0.03\,(syst)]\%$$
$$x_{CP} = [0.27 \pm 0.16\,(stat) \pm 0.04\,(syst)]\%$$
$$\Delta x = [-0.053 \pm 0.070\,(stat) \pm 0.022\,(syst)]\%$$

  - Best precision on x from a single experiment!
- Combination with current global knowledge gives x > 0 at more than 3σ
  - First evidence that masses of D^0 eigenstates differ



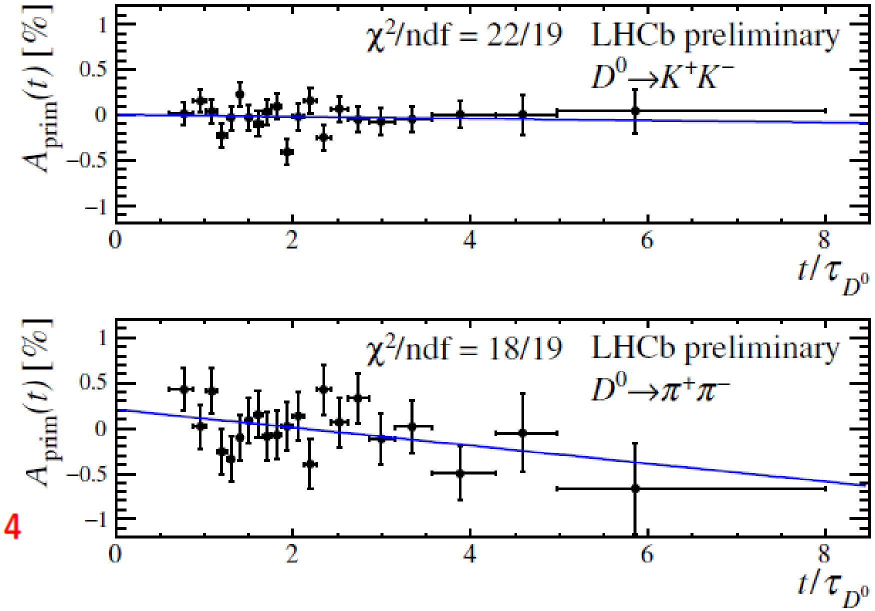
A_Γ in $D^0 \to K^+K^-, \pi^+\pi^-$

- A_Γ probes CPV in mixing and interference

$$A_{CP}(f,t) \approx A_{CP}^{\text{decay}}(f) - \boxed{A_\Gamma} \frac{t}{\tau_{D^0}}$$

  - A linear fit to A_{CP} in bins of D^0 decay time extracts A_Γ as slope parameter
- With Run2 $2\,\text{fb}^{-1}$ data we have

$$A_\Gamma(D^0 \to K^+K^-) = (1.3 \pm 3.5 \pm 0.7) \times 10^{-4}$$
$$A_\Gamma(D^0 \to \pi^+\pi^-) = (11.3 \pm 6.9 \pm 0.8) \times 10^{-4}$$



- A_Γ does not depend on D decay channel, the two values can be combined

$$A_\Gamma(D^0 \to h^+h^-) = (3.4 \pm 3.1 \pm 0.6) \times 10^{-4} \quad (h = K, \pi)$$

- Combining with Run1 results [PRL 118 (2017) 261803]:

$$A_\Gamma(D^0 \to h^+h^-) = (0.9 \pm 2.1 \pm 0.7) \times 10^{-4} \quad (h = K, \pi)$$

A_Γ is consistent with SM!

Search for CPV in $D_{(s)}^+$ decays

- CPV can arise from interference between $c \to d\bar{d}u$ and $c \to s\bar{s}u$
- Simultaneous fits to extract raw asymmetries

$$A_{CP}(D_s^+ \to K_S^0\pi^+) \approx A(D_s^+ \to K_S^0\pi^+) - A(D_s^+ \to \phi\pi^+)$$

$$A_{CP}(D^+ \to K_S^0K^+) \approx A(D^+ \to K_S^0K^+) - A(D^+ \to K_S^0\pi^+) - A(D_s^+ \to K_S^0K^+) + A(D_s^+ \to \phi\pi^+)$$

$$A_{CP}(D^+ \to \phi\pi^+) \approx A(D^+ \to \phi\pi^+) - A(D^+ \to K_S^0\pi^+)$$

- Results with Run2 3.8 fb^{-1} data:

$$\begin{aligned} A_{CP}(D_s^+ \to K_S^0\pi^+) &= (1.3 \pm 1.9 \pm 0.5) \times 10^{-3} \\ A_{CP}(D^+ \to K_S^0K^+) &= (-0.09 \pm 0.65 \pm 0.48) \times 10^{-3} \\ A_{CP}(D^+ \to \phi\pi^+) &= (0.05 \pm 0.42 \pm 0.29) \times 10^{-3} \end{aligned}$$

- Results with Run1 & Run2 combined:

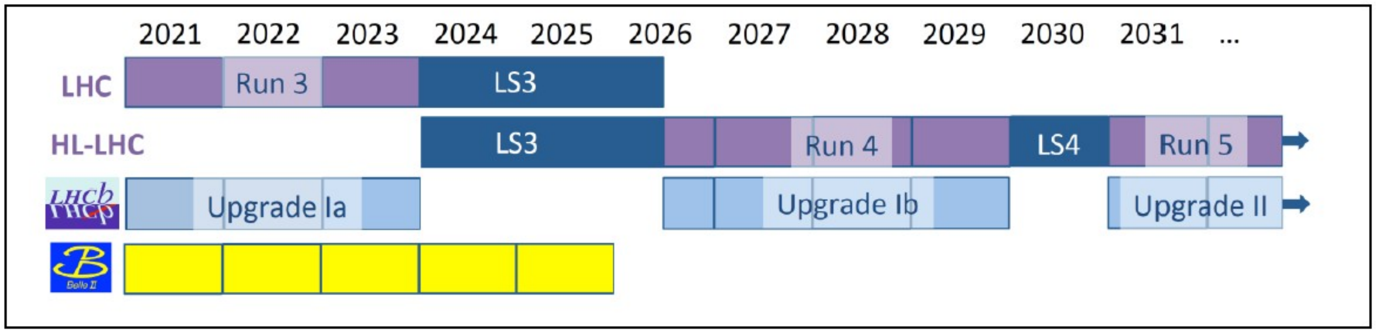
$$\begin{aligned} A_{CP}(D_s^+ \to K_S^0\pi^+) &= (1.6 \pm 1.7 \pm 0.5) \times 10^{-3} \\ A_{CP}(D^+ \to K_S^0K^+) &= (-0.04 \pm 0.61 \pm 0.45) \times 10^{-3} \\ A_{CP}(D^+ \to \phi\pi^+) &= (0.03 \pm 0.40 \pm 0.29) \times 10^{-3} \end{aligned}$$

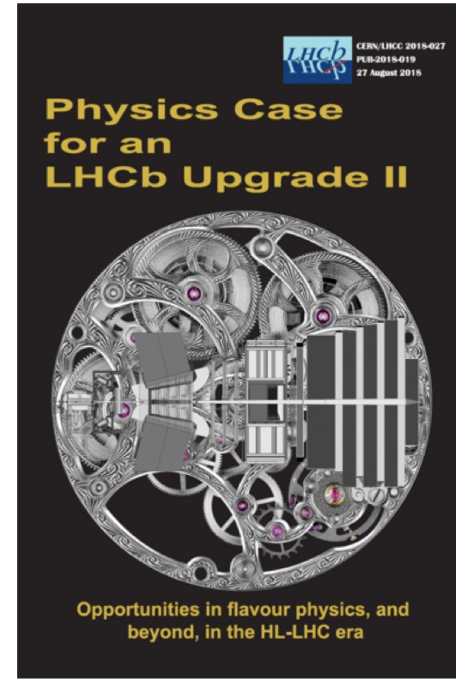
Best A_{CP} measurements on these channels!

[LHCb-PUB-2018-009]

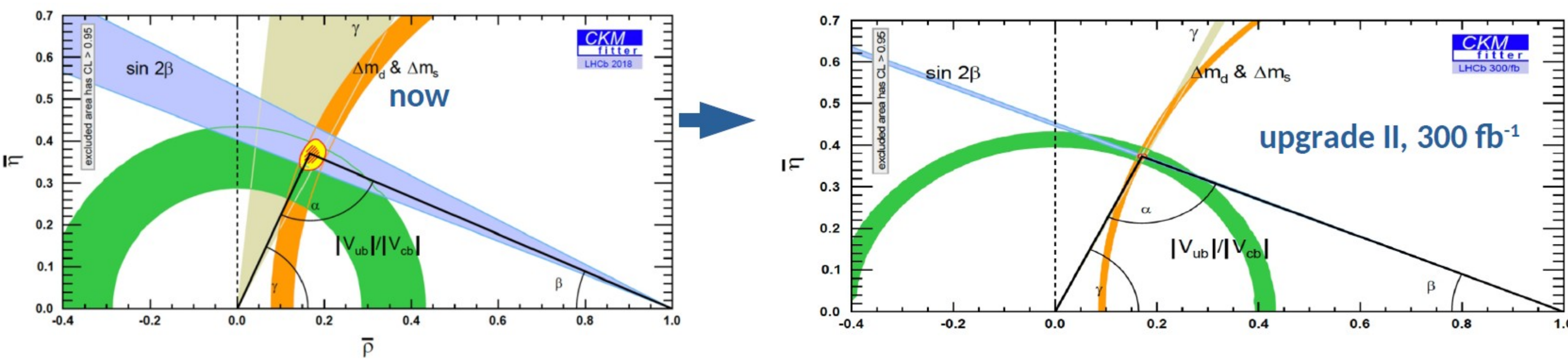
Prospects of LHCb

- Major upgrade phases





  - Upgrade (2020-2023) will provide 3x larger dataset
  - Upgrade (2025-) will be for HL-LHC to collect > 300/fb (30x of current level)



LHCb upgrade and beyond

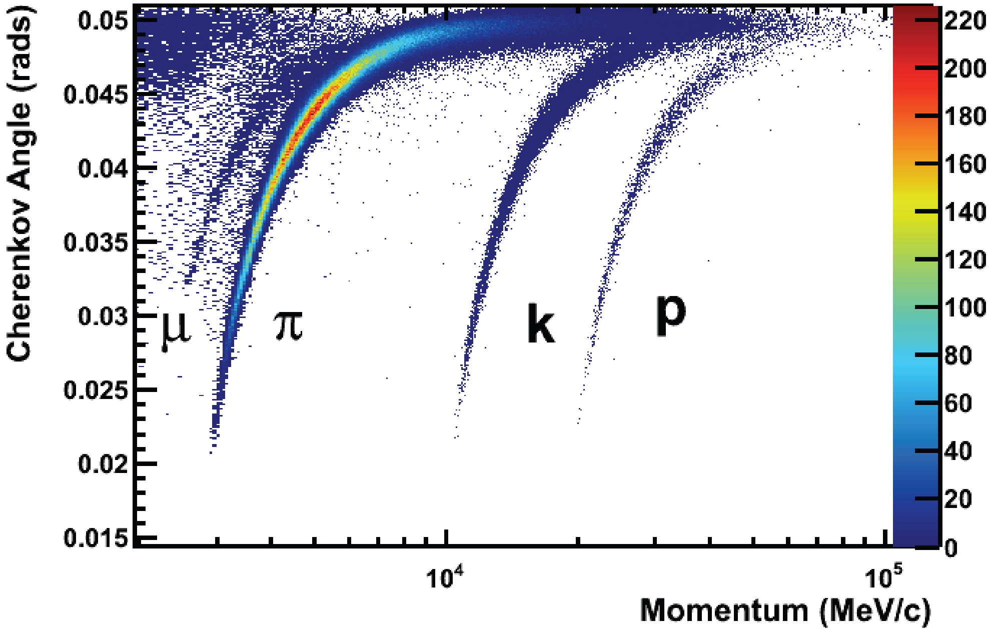
Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1 < q^2 < 6\,\text{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [606]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [607]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [608]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$\boldsymbol{B_s^0, B^0 \to \mu^+\mu^-}$					
$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	90% [264]	34%	–	10%	21% [609]
$\tau_{B_s^0 \to \mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$\boldsymbol{b \to c\ell^-\bar{\nu}_l}$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK - \pi\pi)$	8.5×10^{-4} [610]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x \sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x \sin\phi$ from $D^0 \to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x \sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

Summary

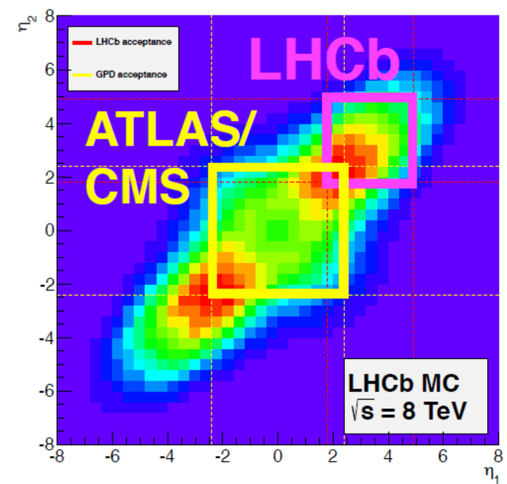
- LHCb has been quite successful in the fields of heavy flavor and CPV
- Many interesting results based on Run1-2 data are still in the pipeline
- LHCb upgrade opens the door to many improvements in precision, so interesting times are still ahead on NP searches

Backup Slides

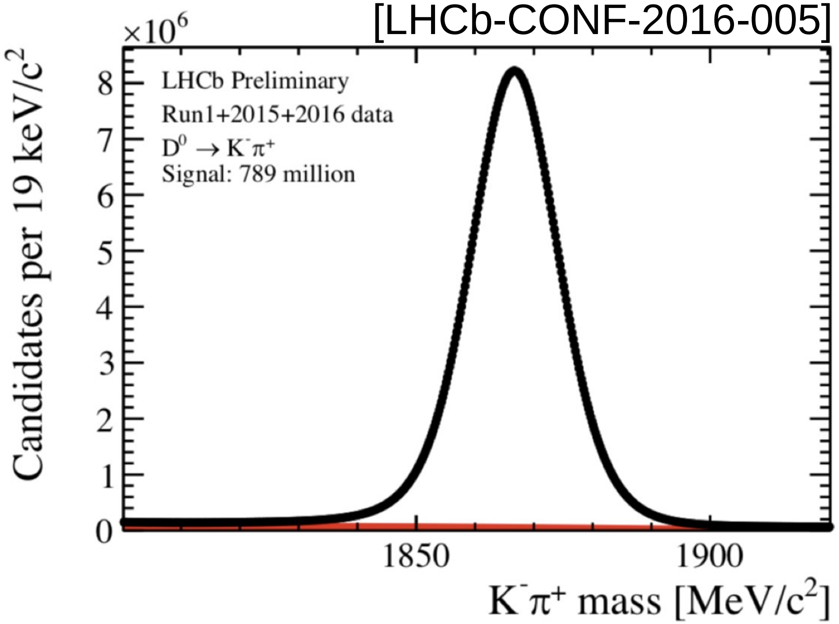
Detector performance



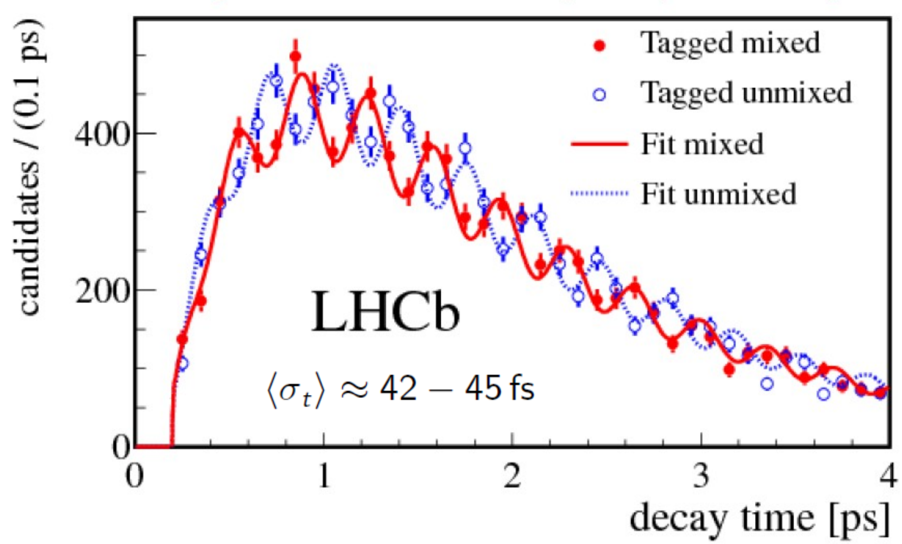
$pp \to b\bar{b}$ cross section



[LHCb-CONF-2016-005]

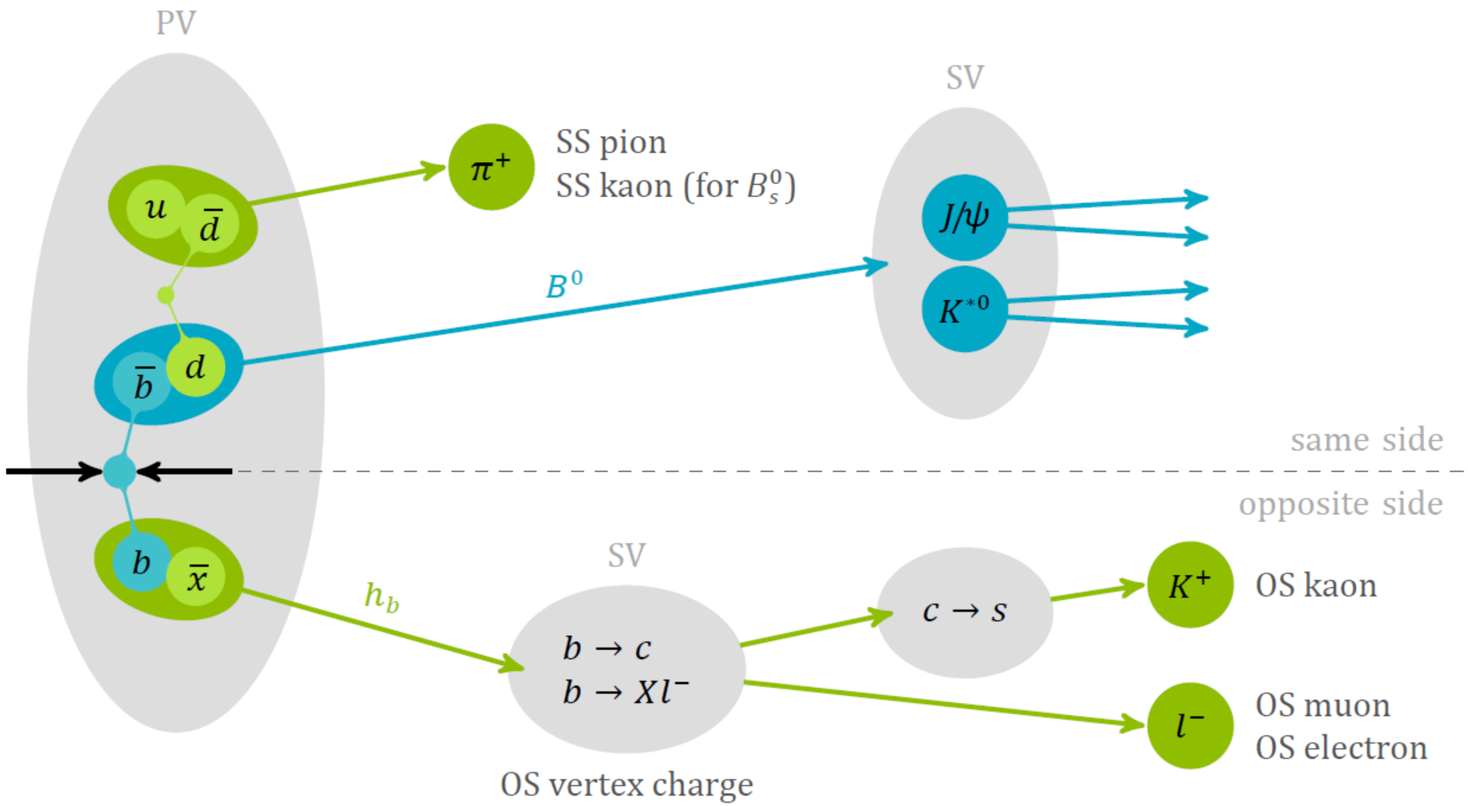


[New J. Phys. 15 (2013) 053021]

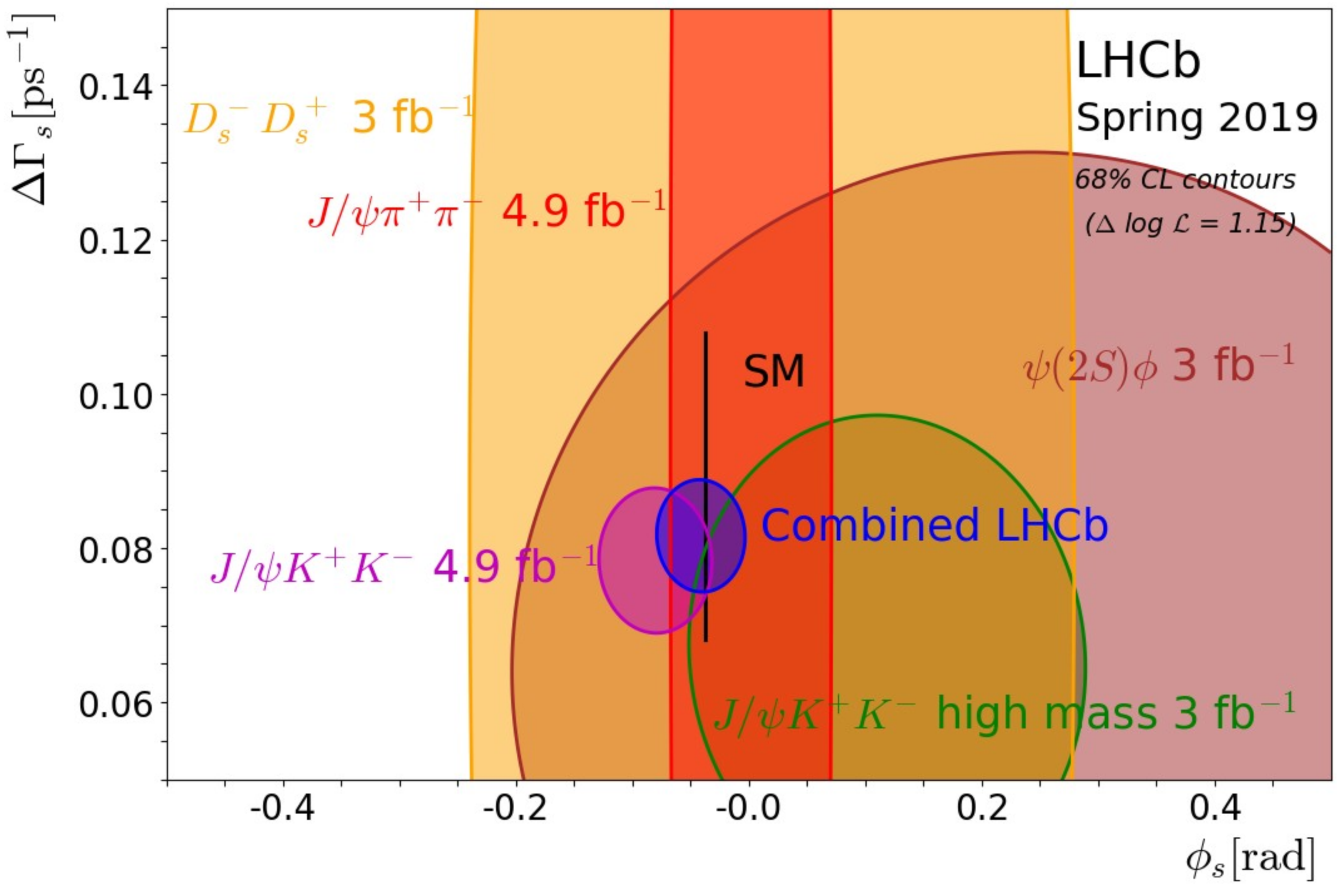


Flavor tagging [PoS(LHCP2018)230]

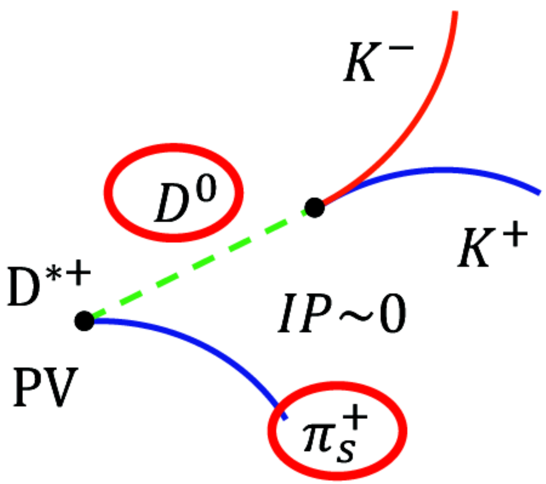
- Tagging in Run 2 improved ⇒ 30% higher tagging power than Run 1
  $\varepsilon_{\text{tag}}(B_s^0 \to J/\psi K^+K^-) = 4.73 \pm 0.34\%$ (vs ≈ 3.73% in Run 1)
  $\varepsilon_{\text{tag}}(B_s^0 \to J/\psi \pi^+\pi^-) = 5.06 \pm 0.38\%$ (vs ≈ 3.89% in Run 1)

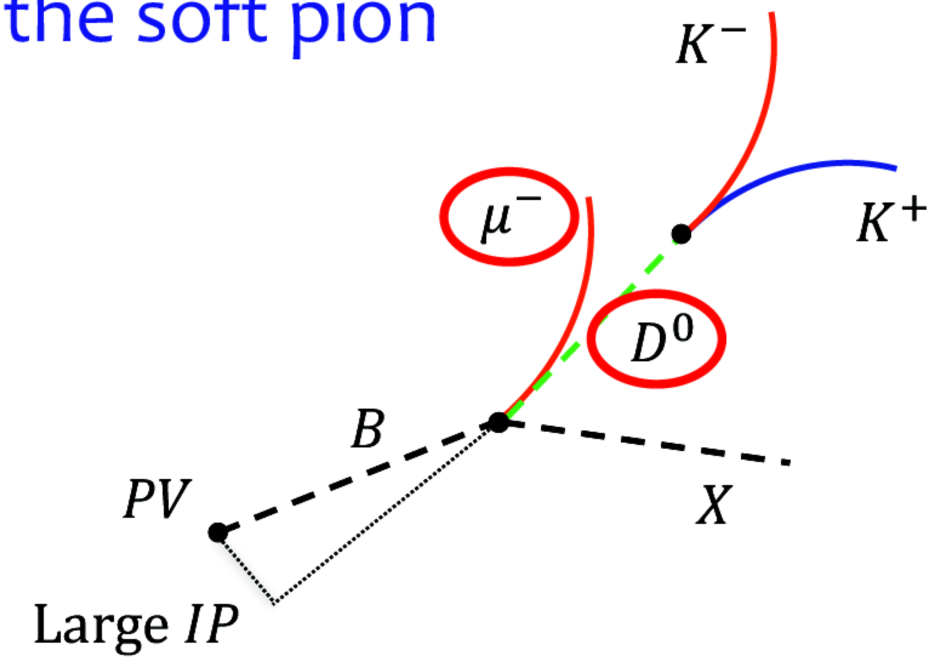


LHCb ϕ_s combination

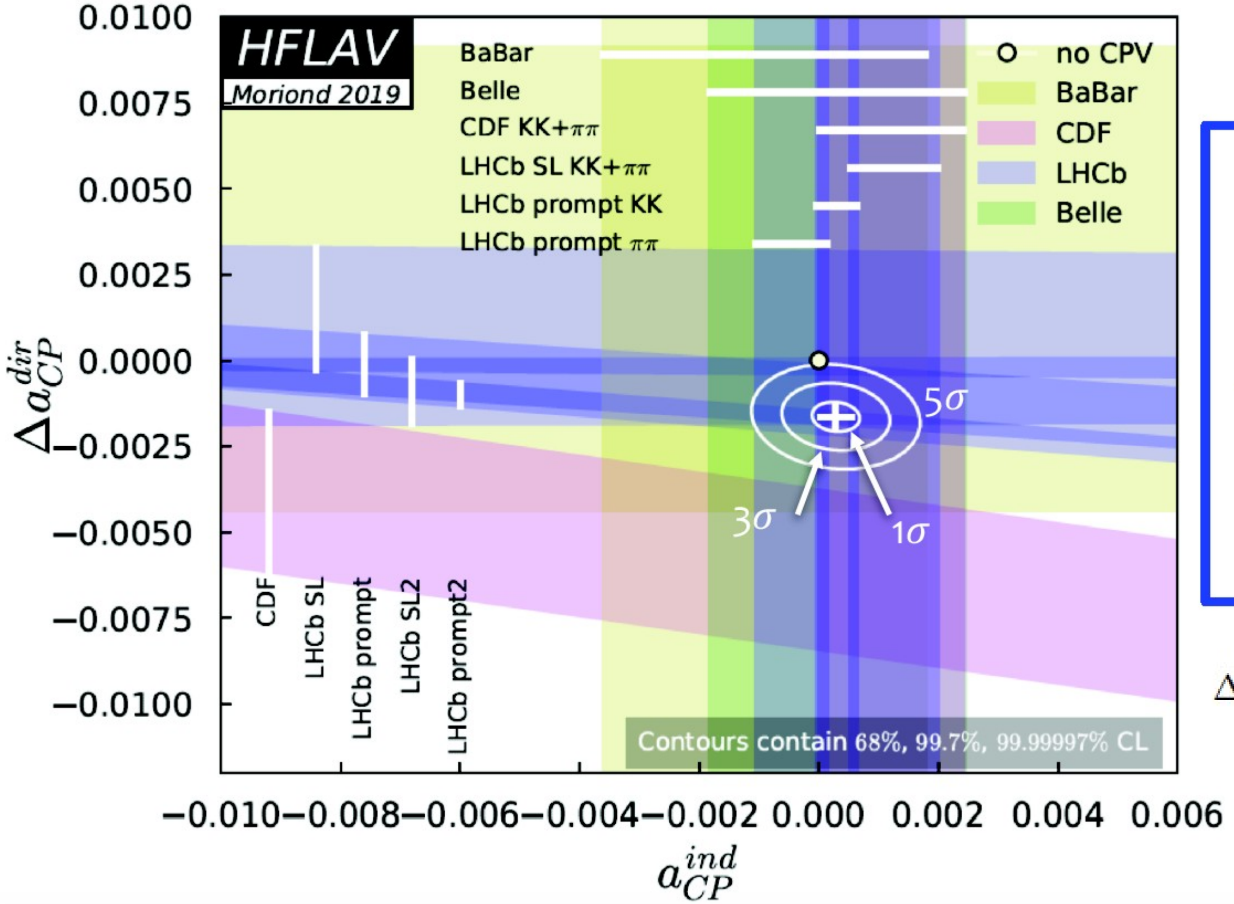


Experimentally we can tag D^0 flavour at production by means of the charge of the muon and the soft pion





HFLAV updates



HFLAV combination

$a_{CP}^{\text{ind}} = (0.028 \pm 0.026)\%$

$\Delta a_{CP}^{\text{dir}} = (-0.164 \pm 0.028)\%$

Consistency with NO CPV hypothesis: 5×10^{-8}

$$\Delta A_{CP} = \left[a_{CP}^{\text{dir}}(K^-K^+) - a_{CP}^{\text{dir}}(\pi^-\pi^+)\right] + \frac{\Delta\langle t\rangle}{\tau} a_{CP}^{\text{ind}}$$

Δa_{CP}^{dir}

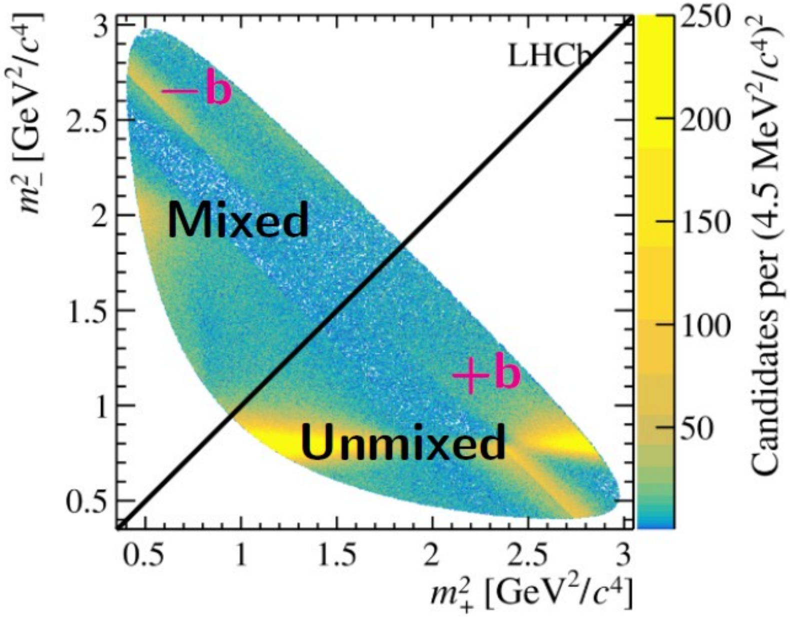
World average dominated by LHCb results

provided by the courtesy of M. Gersabeck

Model-independent Bin-flip method

- Used c_b, s_b from CLEO-c

Phys. Rev. Lett. **122**, 231802



- Bin Dalitz into $\pm b$ about $m_+^2 = m_-^2$
- D decay time into bins j
- Measure ratio of signal in $-b$ and $+b$ in bin j

$$R_{bj}^{\pm} = \frac{r_b\left[1 + \frac{1}{4}t_j^2 Re(z_{CP}^2 - \Delta z^2)\right] + \frac{1}{4}t_j^2 \mid z_{CP} \pm \Delta z \mid^2 + \sqrt{r_b} t_j Re\left[\mathbf{X}_\mathbf{b}^*(z_{CP} \pm \Delta z)\right]}{\left[1 + \frac{1}{4}t_j^2 Re(z_{CP}^2 - \Delta z^2)\right] + r_b \frac{1}{4}t_j^2 \mid z_{CP} \pm \Delta z \mid^2 + \sqrt{r_b} t_j Re\left[\mathbf{X}_\mathbf{b}^*(z_{CP} \pm \Delta z)\right]},$$

where $z_{CP} \pm \Delta z = -(\frac{q}{p})^{\pm}(y + ix)$ and r_b is ratio without mixing $\mathbf{X_b} = \mathbf{c_b} - \mathbf{is_b}$

$R^{\pm}$ **changes with time** $\Rightarrow$ **Mixing**
$R^{+} \neq R^{-}$ $\Rightarrow$ **Indirect CPV**