Beauty to open charm hadronic transitions (*) at LHCb

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on behalf of the LHCb collaboration

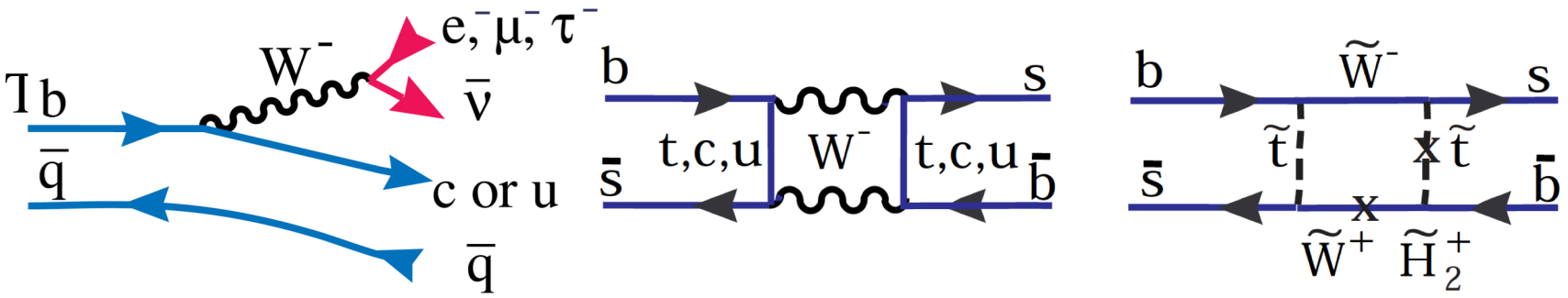
(*)not related to the angle γ, see M. Kenzies' s talk

Physics goals

- Measurement of the angle γ from processes mediated by tree level SM diagrams
- **Other CP violation studies**
- b-hadron lifetimes [see M. Dorigo's talk]
- **Suppressed decays as a probe of new physics**
- Studies of exotic physics (e.g. pentaquark…) [see G. Cavalleri's talk)
- **Constraints of global symmetries probing new physics**

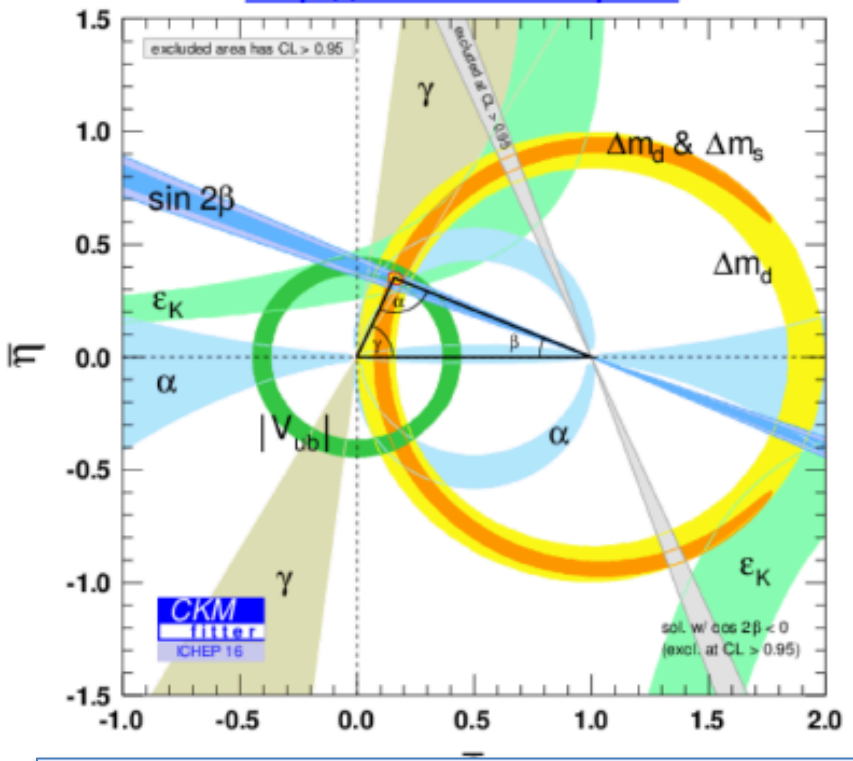
Flavor physics and new physics

- Flavor physics = study of the interactions that distinguish the 3 generations of fermions
  - In Standard Model Yukawa couplings
- New physics manifestations in flavor physics = new couplings or new forces

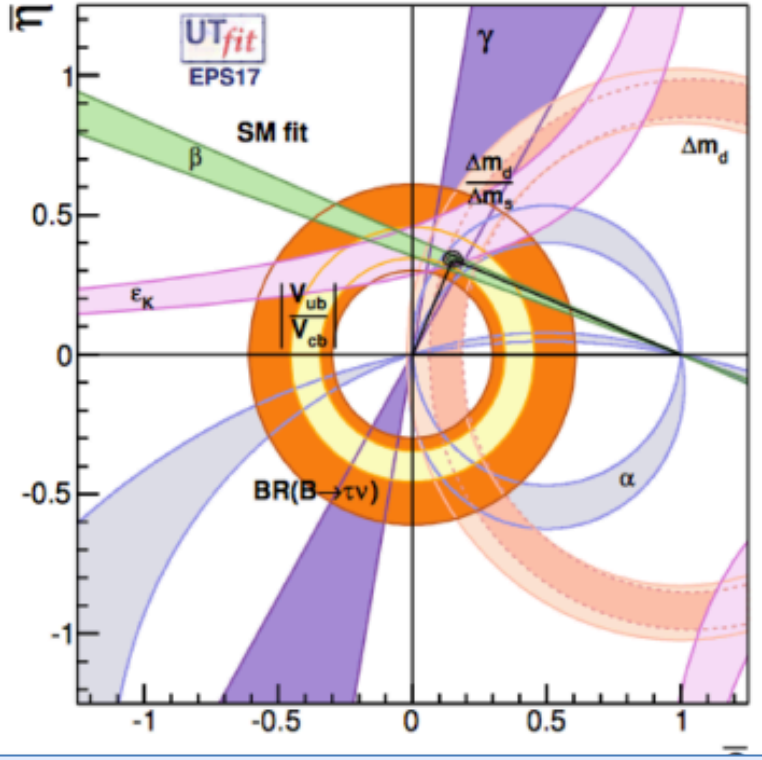


The Cabibbo-Kobayashi-Maskawa matrix and the standard unitarity triangle

http://ckmfitter.in2p3.fr



http://www.utfit.org

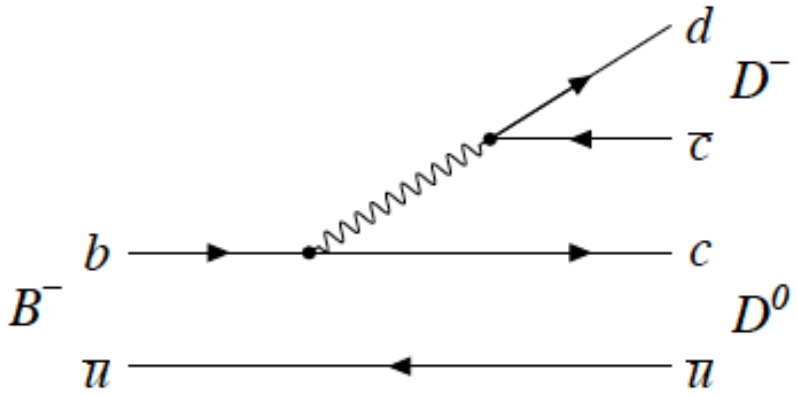


Looks like a triumph of the Standard Model, room for new physics at 10%-15% level

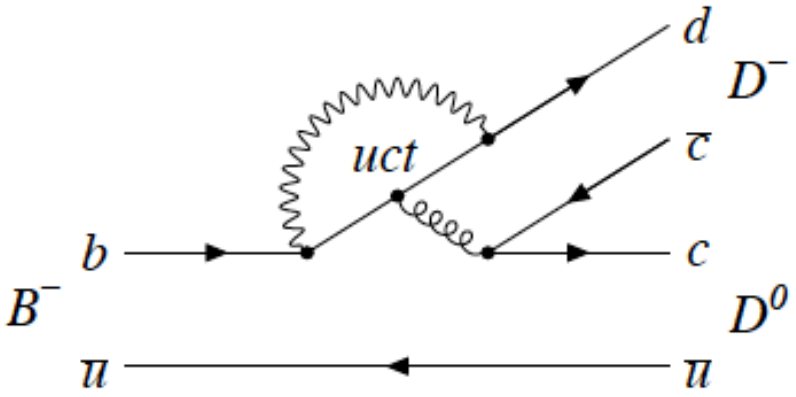
CP violation in $B^- \to D^-_{(s)} D^0$

LHCb-PAPER-2018-007
Run I – $\mathcal{L}$=3fb^{-1}

tree



loop

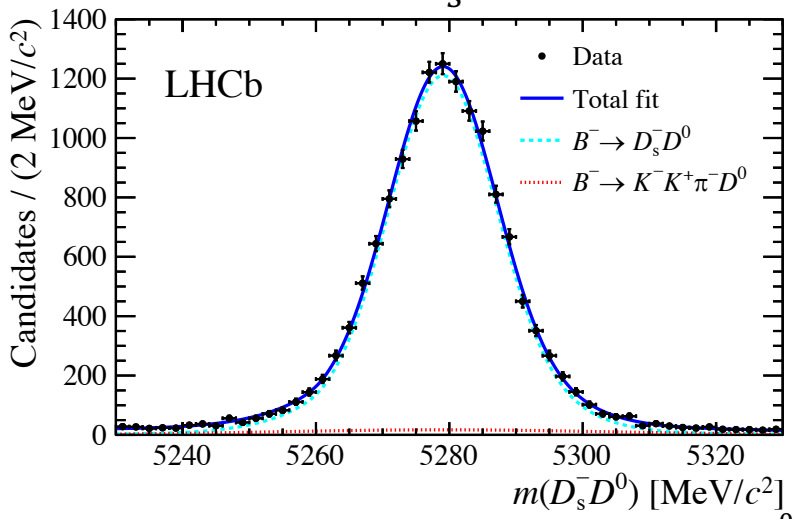


- Loop level diagram expected to be suppressed
- Isospin symmetry relates $\bar{B}^0 \to D^+ D^-$, $\bar{B}^0 \to D^0 \bar{D}^0$, and $B^- \to D^- D^0$

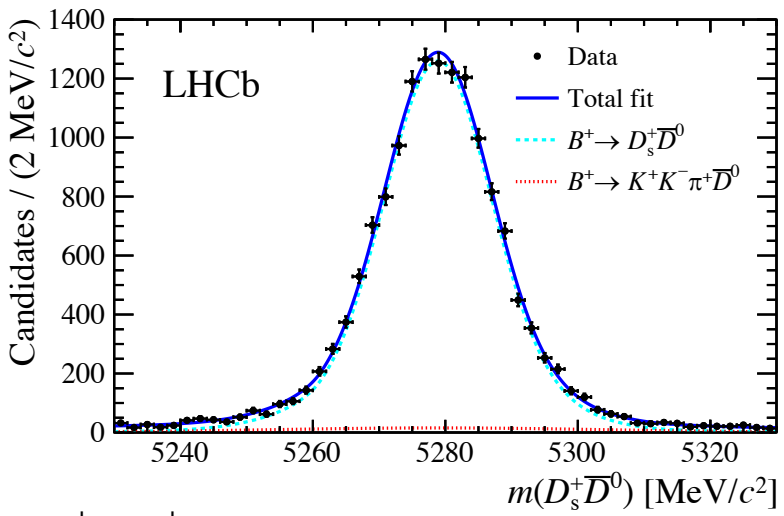
Yields and raw asymmetries

LHCb-paper-2018-007

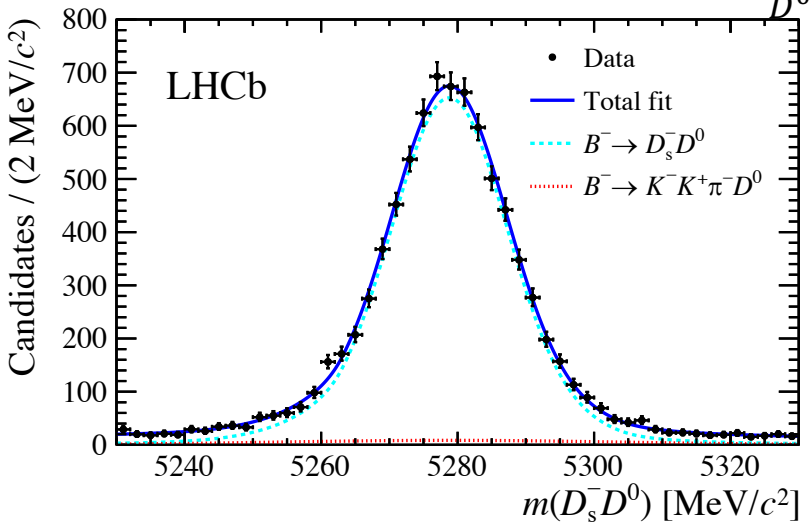
$B^- \to D_s^- D^0$ $D^0 \to K^-\pi^+$



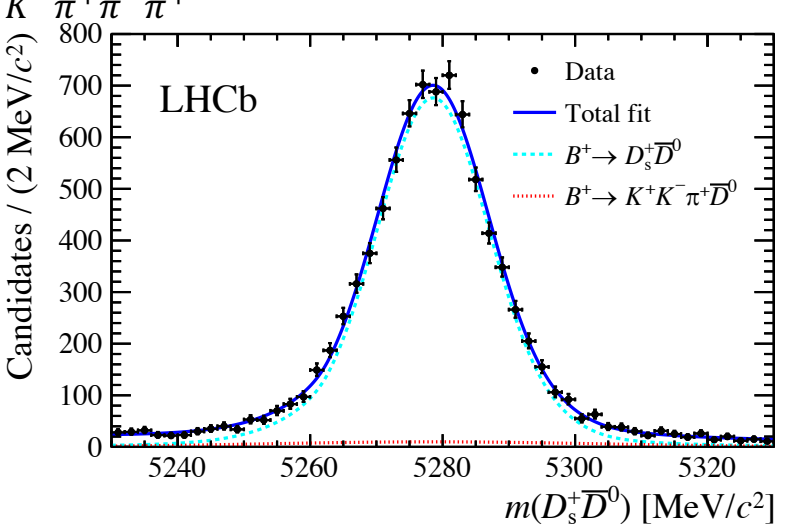
$B^+ \to D_s^+ D^0$ $D^0 \to K^-\pi^+$



$B^- \to D_s^- D^0$ $D^0 \to K^-\pi^+\pi^-\pi^+$



$B^+ \to D_s^+ D^0$ $D^0 \to K^-\pi^+\pi^-\pi^+$



Yields and raw asymmetry $B^- \to D^- D^0$

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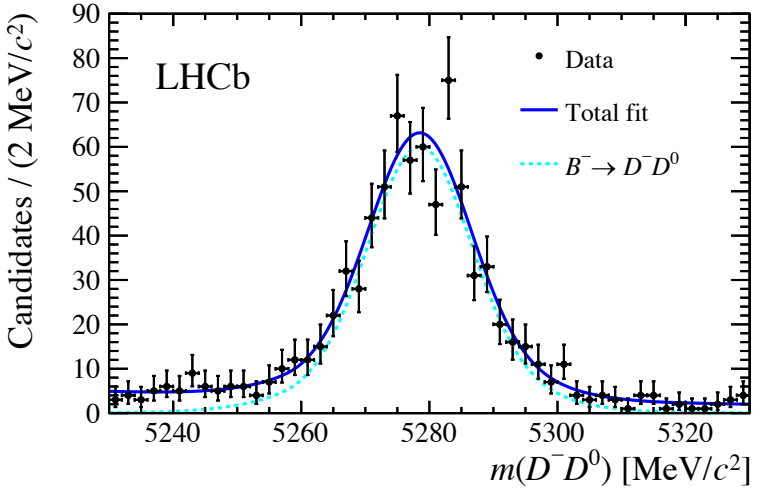
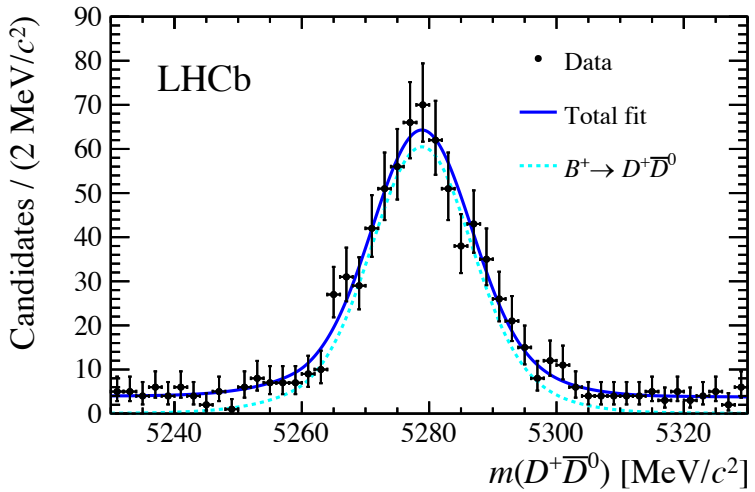
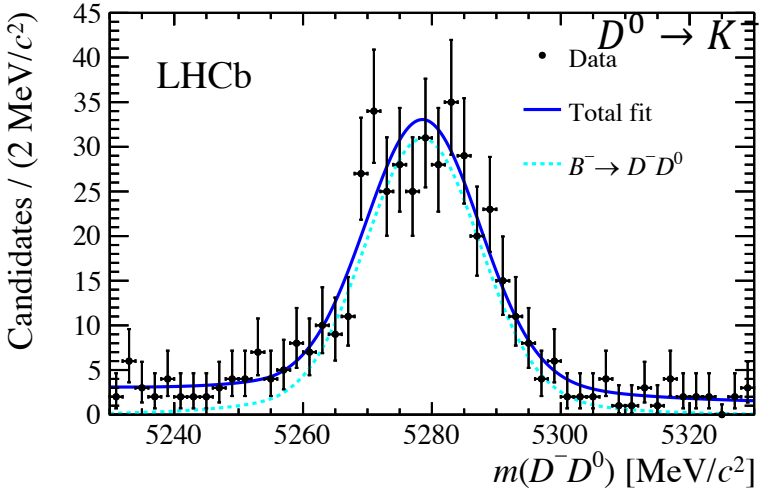
$B^- \to D^- D^0$ $D^0 \to K^- \pi^+$



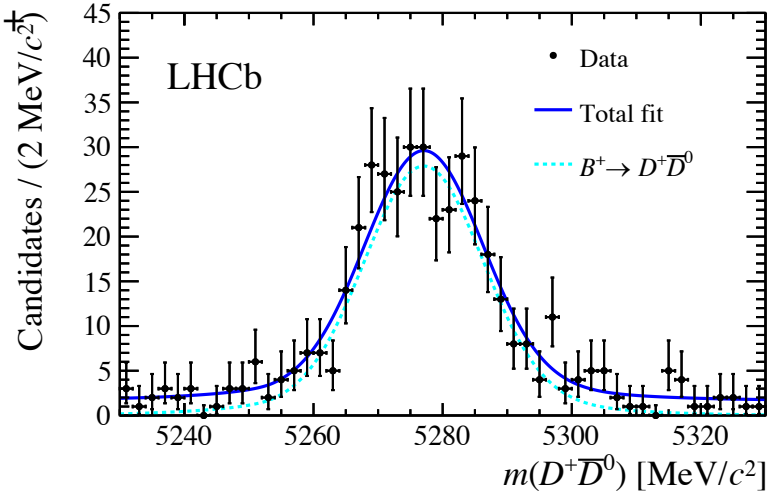
$B^+ \to D^+ D^0$ $D^0 \to K^- \pi^+$



$B^- \to D^- D^0$ $D^0 \to K^- \pi^+ \pi^- \pi^+$



$B^+ \to D^+ D^0$ $D^0 \to K^- \pi^+ \pi^- \pi^+$



$A_{CP} = A_{raw} - A_P - A_D$

Channel	$N(B^-)$	$N(B^+)$	$A_{\rm raw}$
$B^- \to D_s^- D^0$, $D^0 \to K^-\pi^+$	13659 ± 129	14209 ± 132	$(-2.0 \pm 0.7)\%$
$B^- \to D_s^- D^0$, $D^0 \to K^-\pi^+\pi^-\pi^+$	7717 ± 103	7945 ± 104	$(-1.5 \pm 0.9)\%$
$B^- \to D_s^- D^0$, combined	21375 ± 165	22153 ± 168	$(-1.8 \pm 0.5)\%$
$B^- \to D^- D^0$, $D^0 \to K^-\pi^+$	678 ± 32	660 ± 31	$(1.3 \pm 3.3)\%$
$B^- \to D^- D^0$, $D^0 \to K^-\pi^+\pi^-\pi^+$	369 ± 24	345 ± 24	$(3.4 \pm 4.7)\%$
$B^- \to D^- D^0$, combined	1047 ± 40	1005 ± 39	$(2.0 \pm 2.7)\%$

$A_P = (-0.5 \pm 0.4)\%$

From $B^- \to D^0\pi^-$

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Detection asymmetry source	$D_s^- D^0$	$D^- D^0$
Tracking asymmetry	(0.18±0.07)%	(0.18±0.07)%
$K^\pm$ interaction σ	(-1.04±0.16)%	(0. 02±0.01)%
trigger	Negligible (below 0.05%)	
PID	Negligible (below 0.1%)	
$A_P + A_D$	(-1.4±0.5)%	(-0.3±0.4)%
A_{cp}	(-0.4±0.5±0.5)%	(2.3±2.7±0.4)%

CPV in $B^0_{d,s} \to D^+_{(s)} D^-_{(s)}$

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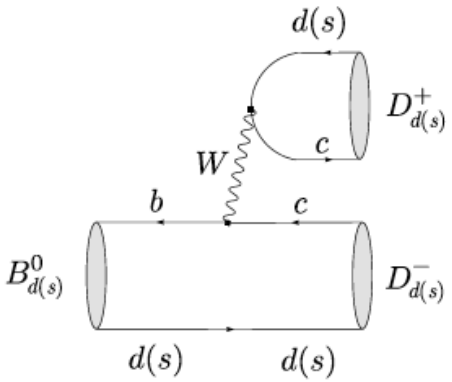
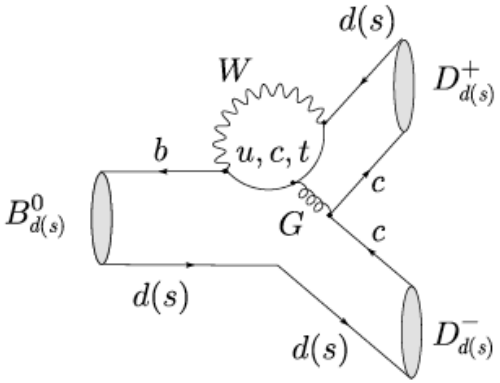
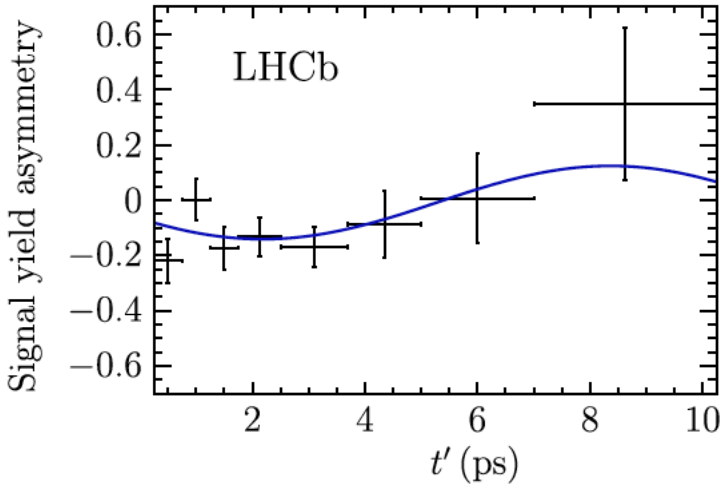
Mixing induced CPV (angle β) + direct CPV







$$\frac{d\Gamma(t,d)}{dt} \propto e^{-t/\tau}[1 - dS\sin(\Delta m t) + dC\cos(\Delta m t)],$$

$$S = -0.54^{+0.17}_{-0.16}(\text{stat}) \pm 0.05(\text{syst}),$$
$$C = \quad 0.26^{+0.18}_{-0.17}(\text{stat}) \pm 0.02(\text{syst})$$

$S_{D^+D^-}$ ($B^0 \to D^+D^-$)

VALUE	DOCUMENT ID		TECN
$-0.76^{+0.15}_{-0.13}$	**OUR AVERAGE** Error includes scale factor of 1.2.		
$-0.54\ ^{+0.17}_{-0.16} \pm 0.05$	AAIJ	2016AN	LHCB
$-1.06\ ^{+0.21}_{-0.14} \pm 0.08$	ROHRKEN	2012	BELL
$-0.63 \pm 0.36 \pm 0.05$	AUBERT	2009C	BABR
$-1.13 \pm 0.37 \pm 0.09$	FRATINA	2007	BELL

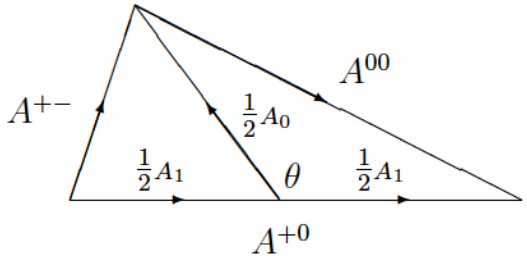
$C_{D^+D^-}$ ($B^0 \to D^+D^-$)

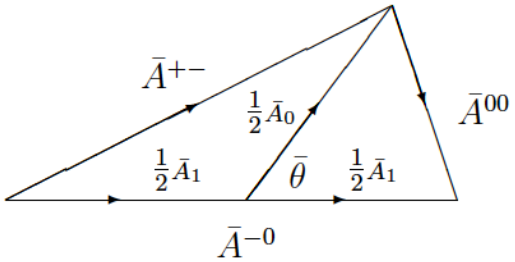
VALUE	DOCUMENT ID		TECN
-0.22 ± 0.24	**OUR AVERAGE** Error includes scale factor of 2.5.		
$0.26\ ^{+0.18}_{-0.17} \pm 0.02$	AAIJ	2016AN	LHCB
$-0.43 \pm 0.16 \pm 0.05$	ROHRKEN	2012	BELL
$-0.07 \pm 0.23 \pm 0.03$	AUBERT	2009C	BABR
$-0.91 \pm 0.23 \pm 0.06$	1 FRATINA	2007	BELL

Isospin relations

Sanda and Xing hep-ph/9702297
Xing hep-ph/9907455
Li, Lu, Sanda and Wang hep-ph/09101424

$$A^{+-} \equiv \langle D^+D^-|\mathcal{H}_{\rm eff}|B_d^0\rangle = \frac{1}{2}(A_1 + A_0)$$
$$A^{00} \equiv \langle D^0\bar{D}^0|\mathcal{H}_{\rm eff}|B_d^0\rangle = \frac{1}{2}(A_1 - A_0)\ ,$$
$$A^{+0} \equiv \langle D^+\bar{D}^0|\mathcal{H}_{\rm eff}|B_u^+\rangle = A_1\ ;$$





- Branching fractions and CP asymmetries provide important constraints to the hadronic matrix elements
- Relationship with $B_s^0 \to D_s^+D_s^-$ Fleischer EUR. Phys.J c51 (2007)
- Approach generalized to SU(3) by Jung & Schacht PRD 91,034027 – small CP asymmetry measured in $B^- \to D^-D^0$ favors SM expectations

$B^+ \to D_s^+ K^+ K^-$ and $B^+ \to D_s^+ \varphi$

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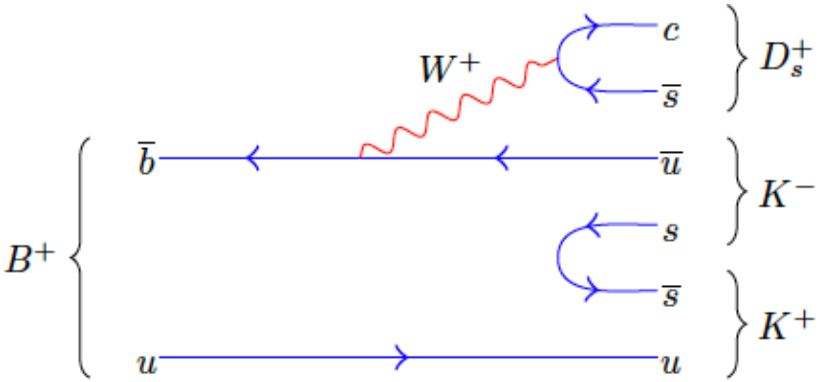
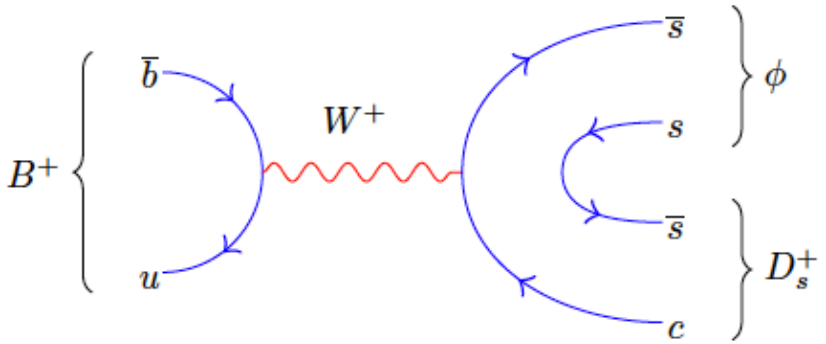


$b \to u$ *transition*



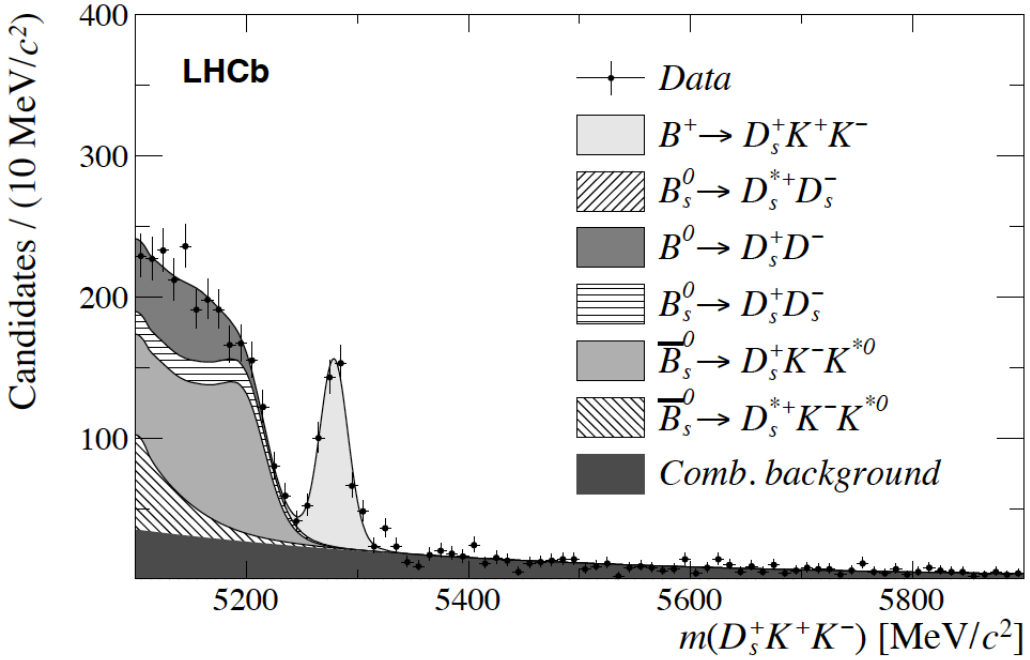
Annihilation diagram
+$b \to u$ *transition*
At annihilation vertex

Expected to be highly suppressed in the Standard Model [$B(D_s\phi) \sim (1\text{-}7)\times10^{-7}$]

Possible enhancements,e.g. SUSY with R parity??? CPV enhancement possible too

LHCb-PAPER-2017-032

$B^+ \to D_s^+ K^+ K^-$



- Normalization channel $B^+ \to D_s^+ \overline{D}^0, \overline{D}^0 \to K^+ K^-$
- Yields corrected on a per-candidate basis

$$B(B^+ \to D_s^+ K^+ K^-) = (7.1 \pm 0.5 \pm 0.6 \pm 0.7) \times 10^{-6}$$

$B^+ \to D_s^+ \varphi$

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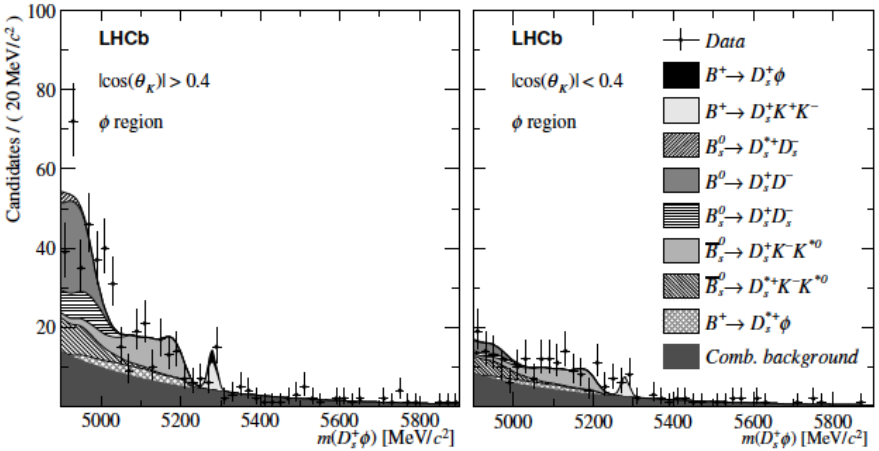
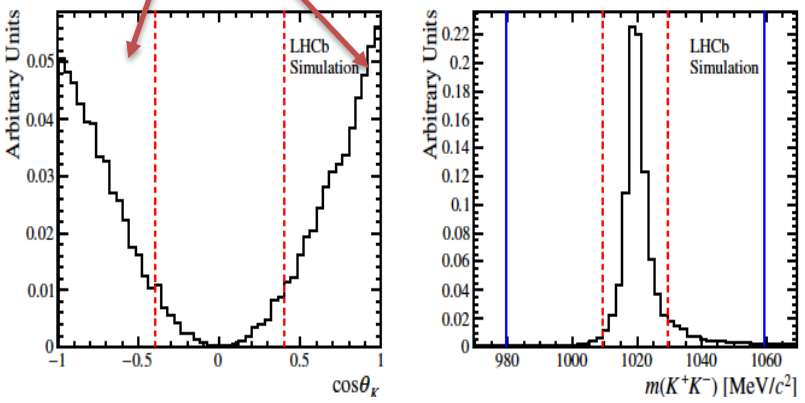
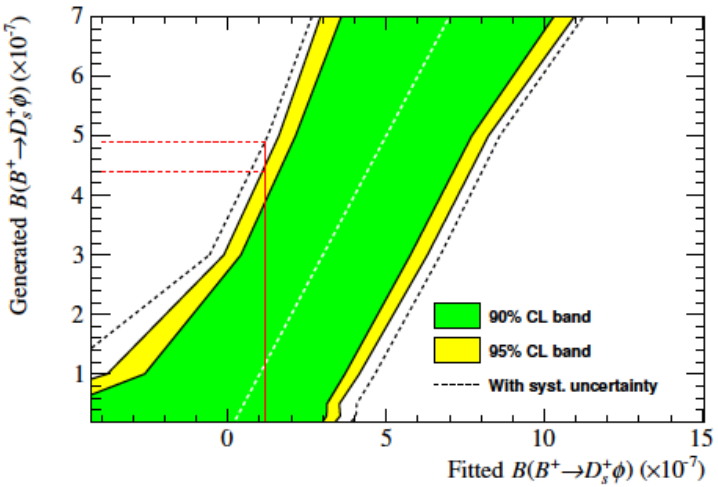
Signal enriched regions







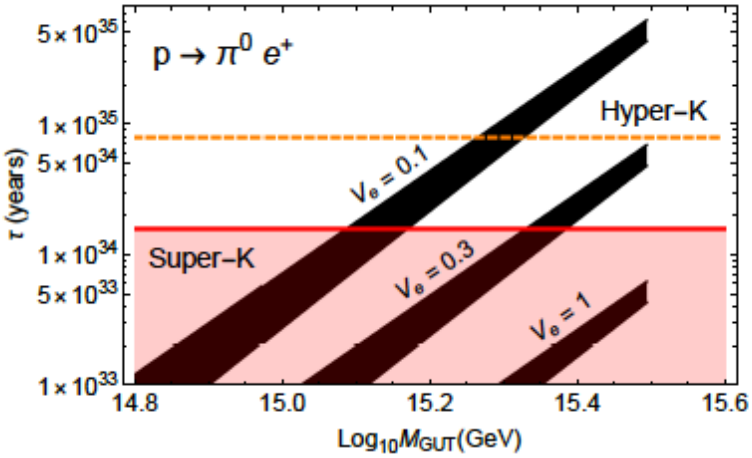
$$\mathcal{B}(B^+ \to D_s^+\phi) = (1.2^{+1.6}_{-1.4} \pm 0.8 \pm 0.1) \times 10^{-7},$$

$$\mathcal{B}(B^+ \to D_s^+\phi) < 4.9 \times 10^{-7} \ (4.2 \times 10^{-7})$$

@95%(90%)CL

BARYON NUMBER VIOLATION

Perez,Gross, Murgui
arXiV:1804.07831



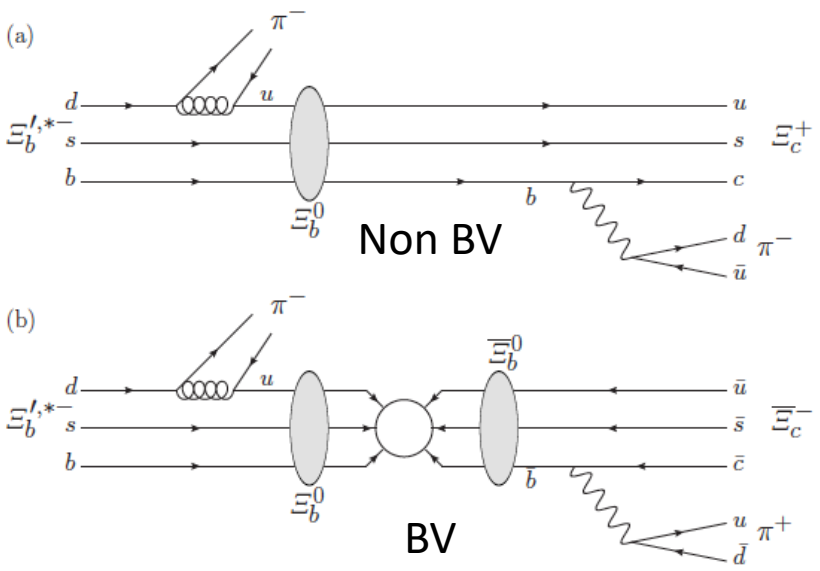
- Matter dominated universe requires baryon number violation (Sakharov)
- Heavy baryon oscillations suggested as possible mechanism for baryogenesis [D. McKeen, A. Nelson, arXiV:1512.05359, K. Aitken et al, arXiV:1708.01259]
- Proton decay has proven elusive to experimental detection, beyond expectations from the simplest grand unified theories
- Suggestion that new BNV couplings could be flavor diagonal, e.g. 6-fermion operator that couples two fermions from each generation.

This 6-quark operator could allow BNV & be consistent with experimental limit on proton decay lifetime.

Search for BNV Ξ_b^0 oscillations

LHCb-PAPER-2017-023
Run I 3fb^{-1}

- $\Xi_b^0 = bsu$ only flavor diagonal baryon observed to decay weakly
- Flavor tag provided by charge of the pion in $\Xi_b'^-$
- Formalism the same as meson oscillations, need to take into account B field because of non-zero magnetic moment of the baryon $\Delta E = 2\vec{\mu} \cdot B$
- $|\Delta E| t/2 \leq 10^{-4}$



$$R(t) \equiv \frac{P_{X\to\overline{X}}(t)}{P_{X\to X}(t)} = \tan^2(t/\tau_{\rm mix}) \simeq \frac{t^2}{\tau_{\rm mix}^2} \equiv (\omega t)^2,$$

Assuming negligible BNV in decay $\omega \sim \frac{\Delta M}{2}$

Results

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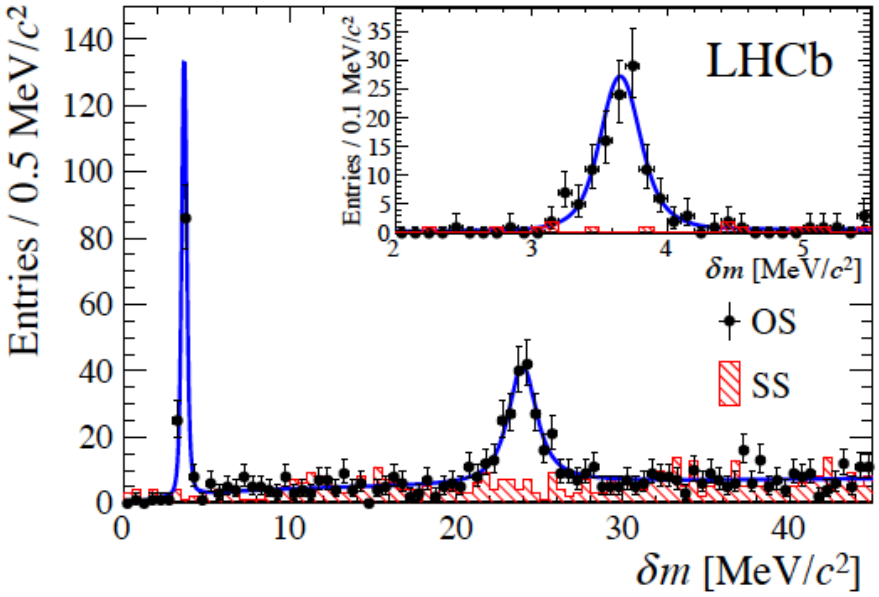
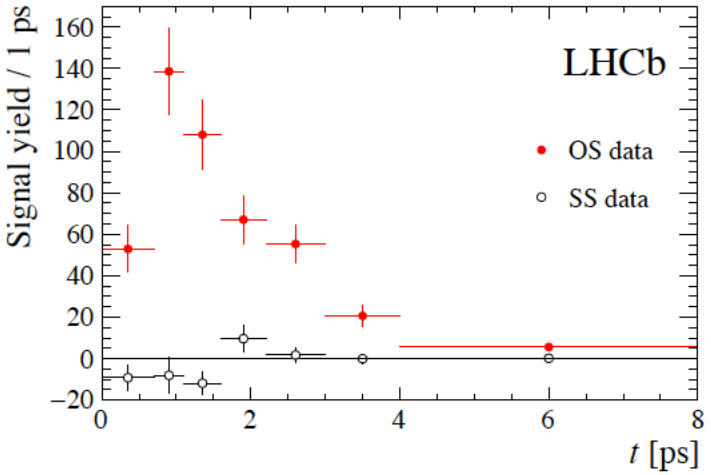
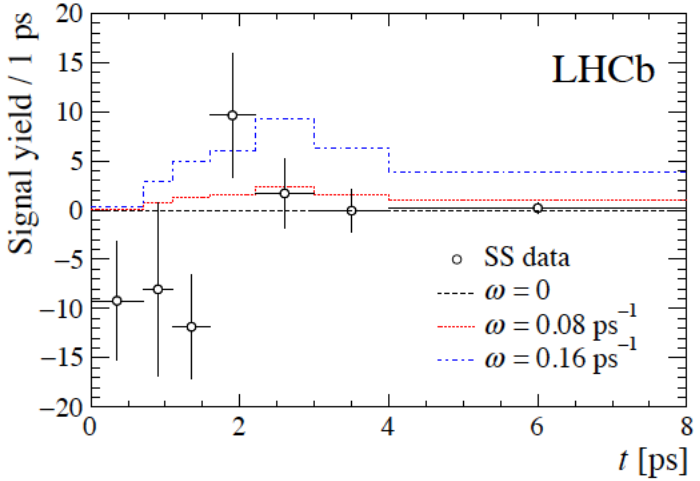






$\omega < 0.08 ps^{-1}$ or $\tau_{mix} > 13$ ps, rules out model by Kuzmin *"Might fast B-violating transitions be found soon?..."* *arXiv:hep-ph/9609253*

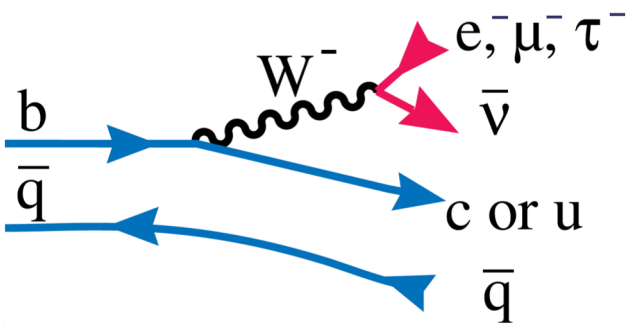
Conclusions

- The study of open-charm hadronic b-hadron decays allows us to elucidate the nature of CPV within and beyond the Standard Model
- New physics manifestations may arise in decays suppressed in the Standard Model, although no evidence has yet been found
- The vast array of b-hadrons produced at LHCb allows for the exploration of many fundamental symmetries
- **Stay tuned!**

THE END

Quark Mixing & CKM Matrix

The charged current couples the "up-type quarks" with a linear combination of "down-type" quarks



- Described by CKM matrix

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

λ=0.225, A=0.8, constraints on ρ & η *summarized in the standard CKM triangle*

$\bar{b} \to \bar{q}q\bar{q}'$	$B^0 \to f$	$B_s^0 \to f$	CKM dependence of A_f	Suppression
$\bar{b} \to \bar{c}c\bar{s}$	ψK_S	$\psi\phi$	$(V_{cb}^* V_{cs})T + (V_{ub}^* V_{us})P^u$	loop $\times\ \lambda^2$
$\bar{b} \to \bar{s}s\bar{s}$	ϕK_S	$\phi\phi$	$(V_{cb}^* V_{cs})P^c + (V_{ub}^* V_{us})P^u$	λ^2
$\bar{b} \to \bar{u}u\bar{s}$	$\pi^0 K_S$	K^+K^-	$(V_{cb}^* V_{cs})P^c + (V_{ub}^* V_{us})T$	λ^2/loop
$\bar{b} \to \bar{c}c\bar{d}$	D^+D^-	ψK_S	$(V_{cb}^* V_{cd})T + (V_{tb}^* V_{td})P^t$	loop
$\bar{b} \to \bar{s}s\bar{d}$	$K_S K_S$	ϕK_S	$(V_{tb}^* V_{td})P^t + (V_{cb}^* V_{cd})P^c$	$\lesssim 1$
$\bar{b} \to \bar{u}u\bar{d}$	$\pi^+\pi^-$	$\rho^0 K_S$	$(V_{ub}^* V_{ud})T + (V_{tb}^* V_{td})P^t$	loop
$\bar{b} \to \bar{c}u\bar{d}$	$D_{CP}\pi^0$	$D_{CP}K_S$	$(V_{cb}^* V_{ud})T + (V_{ub}^* V_{cd})T'$	λ^2
$\bar{b} \to \bar{c}u\bar{s}$	$D_{CP}K_S$	$D_{CP}\phi$	$(V_{cb}^* V_{us})T + (V_{ub}^* V_{cs})T'$	$\lesssim 1$