γ measurements from $B^0_s \rightarrow D_s^{\pm} K^{\mp}(\pi\pi)$ @ LHCb

S. Hansmann-Menzemer, Heidelberg University & CERN

(with a lot of help from N. Tuning NIKHEF)

on behalf of the LHCb collaboration

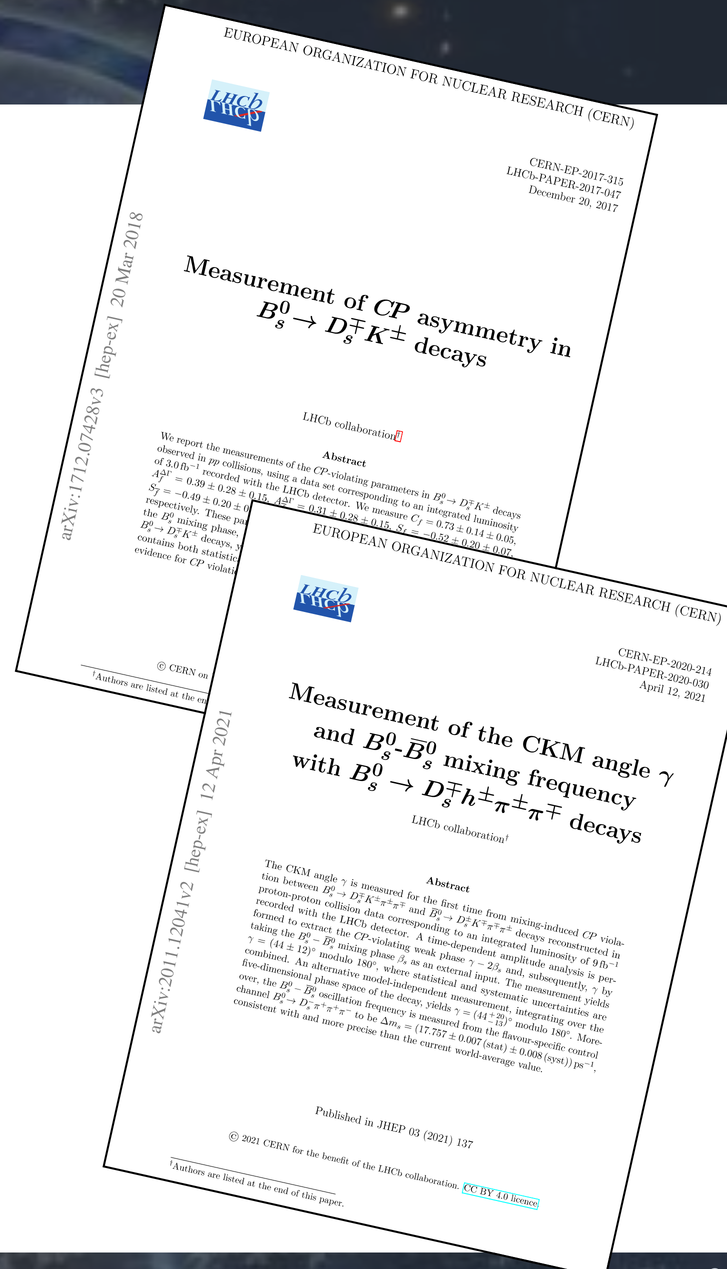
31.5.2022, Siegen

Outline

- Introduction
- Formalism

- $B_s^0 \to D^{\pm}_s K^{\mp}$
  - 3 fb^{-1} , JHEP 03 (2018) 059, arXiv:1712.07428
- $B_s^0 \to D^{\pm}_s K^{\mp} \pi^{\pm} \pi^{\pm}$
  - 9 fb^{-1}, JHEP 03 (2021) 137, arXiv:2011.12041

- Comparison
- Outlook


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2017-315
LHCb-PAPER-2017-047
December 20, 2017

arXiv:1712.07428v3 [hep-ex] 20 Mar 2018

Measurement of CP asymmetry in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

LHCb collaboration†

Abstract

We report the measurements of the CP-violating parameters in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays observed in pp collisions, using a data set corresponding to an integrated luminosity of 3.0 fb^{-1} recorded with the LHCb detector. We measure $C_f = 0.73 \pm 0.14 \pm 0.05$, $A_f^{\Delta\Gamma} = 0.39 \pm 0.28 \pm 0.15$, $A_{\bar f}^{\Delta\Gamma} = 0.31 \pm 0.28 \pm 0.15$, $S_f = -0.52 \pm 0.20 \pm 0.07$, $S_{\bar f} = -0.49 \pm 0.20 \pm 0$ …

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2020-214
LHCb-PAPER-2020-030
April 12, 2021

arXiv:2011.12041v2 [hep-ex] 12 Apr 2021

Measurement of the CKM angle γ and B_s^0-$\overline{B}_s^0$ mixing frequency with $B_s^0 \to D_s^{\mp} h^{\pm} \pi^{\pm} \pi^{\mp}$ decays

LHCb collaboration†

Abstract

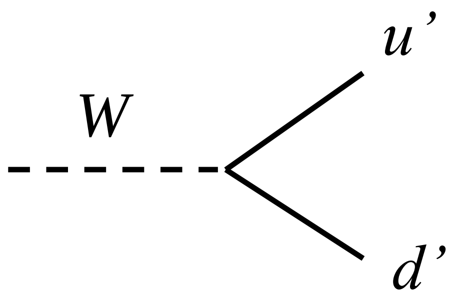
The CKM angle γ is measured for the first time from mixing-induced CP violation between $B_s^0 \to D_s^{\mp} K^{\pm} \pi^{\pm} \pi^{\mp}$ and $\overline{B}_s^0 \to D_s^{\pm} K^{\mp} \pi^{\mp} \pi^{\pm}$ decays reconstructed in proton-proton collision data corresponding to an integrated luminosity of 9 fb^{-1} recorded with the LHCb detector. A time-dependent amplitude analysis is performed to extract the CP-violating weak phase $\gamma - 2\beta_s$ and, subsequently, γ by taking the $B_s^0 - \overline{B}_s^0$ mixing phase β_s as an external input. The measurement yields $\gamma = (44 \pm 12)^\circ$ modulo 180°, where statistical and systematic uncertainties are combined. An alternative model-independent measurement, integrating over the five-dimensional phase space of the decay, yields $\gamma = (44^{+20}_{-13})^\circ$ modulo 180°. Moreover, the $B_s^0 - \overline{B}_s^0$ oscillation frequency is measured from the flavour-specific control channel $B_s^0 \to D_s^- \pi^+ \pi^+ \pi^-$ to be $\Delta m_s = (17.757 \pm 0.007\,(\text{stat}) \pm 0.008\,(\text{syst}))\,\text{ps}^{-1}$, consistent with and more precise than the current world-average value.

Published in JHEP 03 (2021) 137

†Authors are listed at the end of this paper.

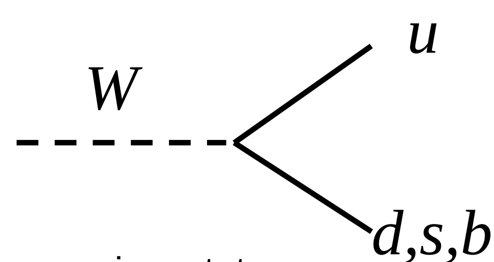
CKM: A Quick Reminder

matrix to transform weak- and mass-eigenstates



weak eigenstates

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix}.$$



mass eigenstates

matrix has imaginary numbers

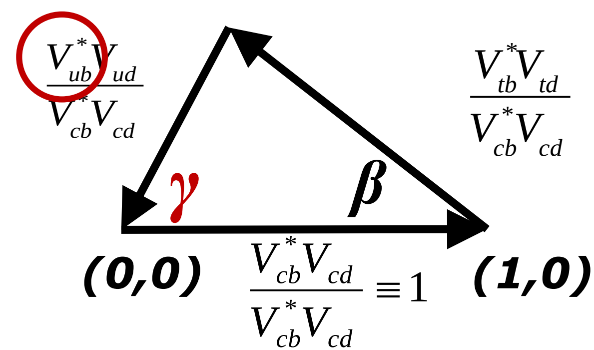
(first order approximation)

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

matrix is unitary

$$V^{+}V = \begin{pmatrix} V^*_{ud} & V^*_{cd} & V^*_{td} \\ V^*_{us} & V^*_{cs} & V^*_{ts} \\ V^*_{ub} & V^*_{cb} & V^*_{tb} \end{pmatrix} \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = 0$$



LHC-B Letter-of-Intent 1995

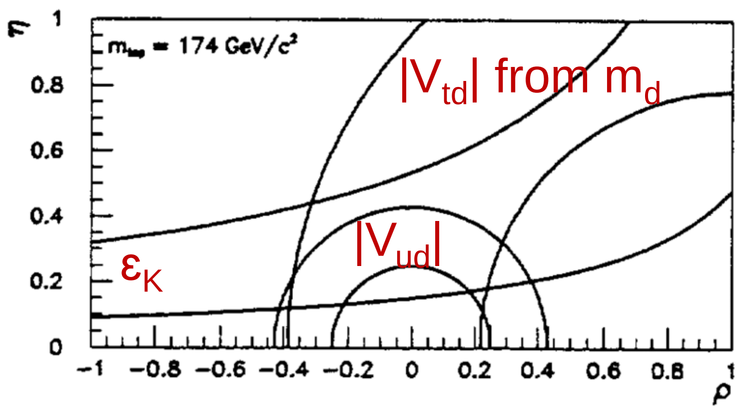
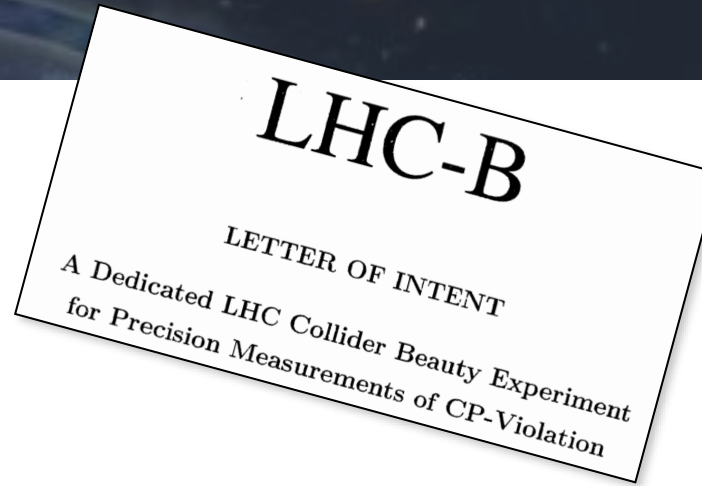


Figure 2.1: Limits on the CKM parameters (1σ) ρ and η for $m_t = 174$ GeV.



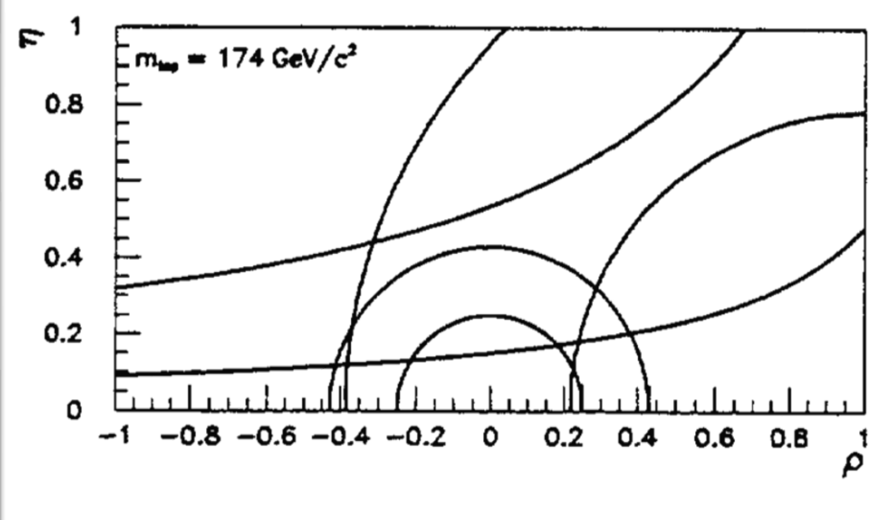
LHC-B

LETTER OF INTENT

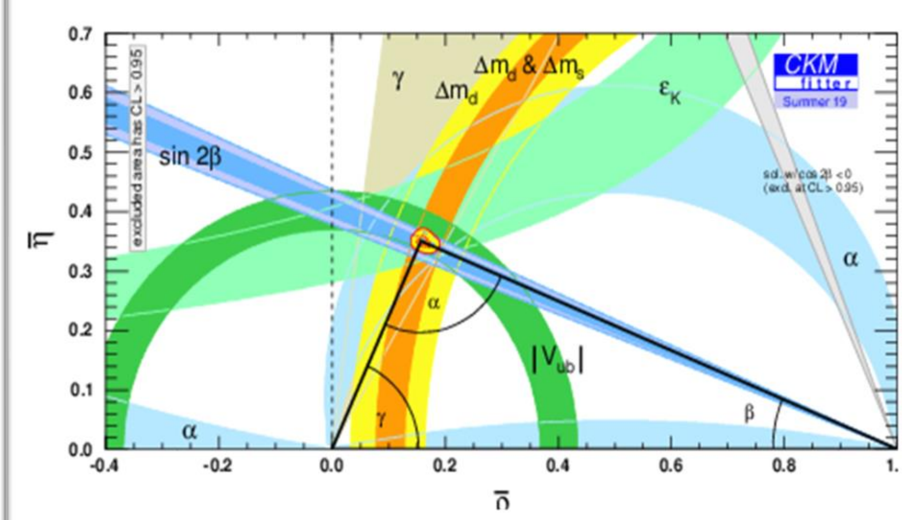
A Dedicated LHC Collider Beauty Experiment
for Precision Measurements of CP-Violation

γ Combinations

1995



2021



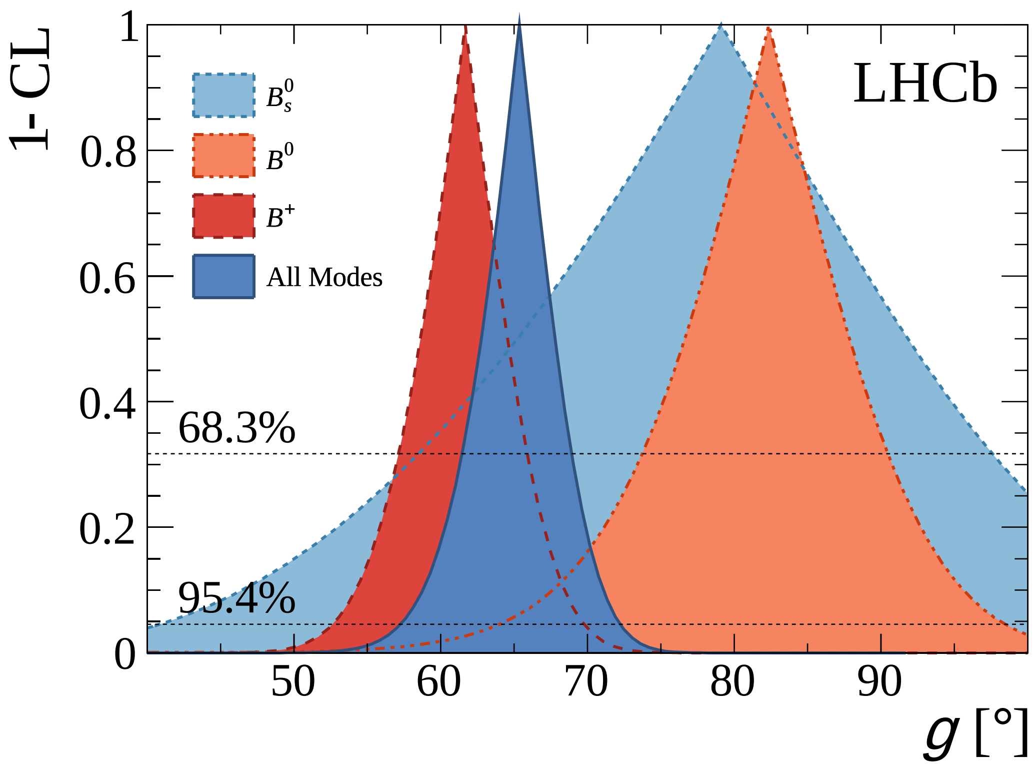
from direct measurements (tree level decays): $(72.1^{+4.1}_{-4.5})^{o}$

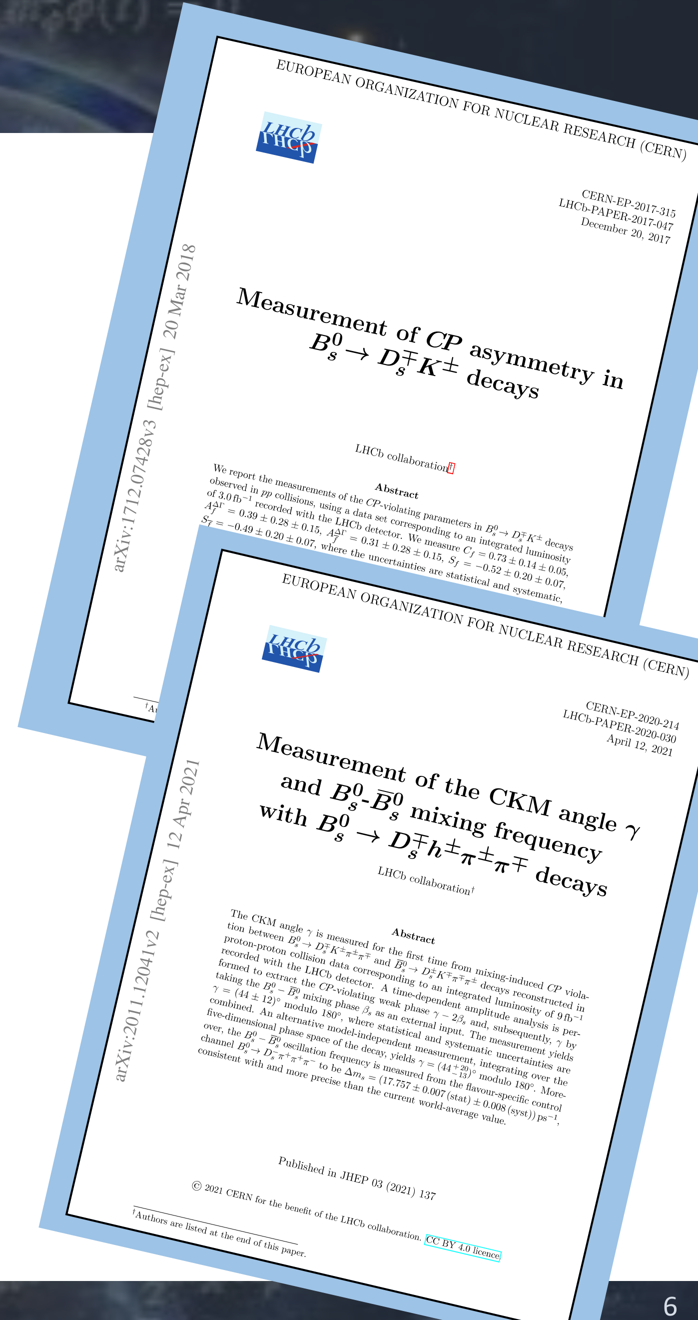
from indirecte measurements (loop induced measurements):

$(65.7\ ^{+0.9}_{-2.7})^{o}$ (CKM fitter) or $(65.8 \pm 2.2)^{o}$ (UT fitter)

LHCb γ Combination

JHEP 12 (2021) 141




EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2017-315
LHCb-PAPER-2017-047
December 20, 2017

arXiv:1712.07428v3 [hep-ex] 20 Mar 2018

Measurement of CP asymmetry in $B_s^0 \to D_s^\mp K^\pm$ decays

LHCb collaboration†

Abstract

We report the measurements of the CP-violating parameters in $B_s^0 \to D_s^\mp K^\pm$ decays observed in pp collisions, using a data set corresponding to an integrated luminosity of 3.0 fb^{-1} recorded with the LHCb detector. We measure $C_f = 0.73 \pm 0.14 \pm 0.05$, $A_f^{\Delta\Gamma} = 0.39 \pm 0.28 \pm 0.15$, $A_{\bar{f}}^{\Delta\Gamma} = 0.31 \pm 0.28 \pm 0.15$, $S_f = -0.52 \pm 0.20 \pm 0.07$, $S_{\bar{f}} = -0.49 \pm 0.20 \pm 0.07$, where the uncertainties are statistical and systematic, ...

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2020-214
LHCb-PAPER-2020-030
April 12, 2021

arXiv:2011.12041v2 [hep-ex] 12 Apr 2021

Measurement of the CKM angle γ and B_s^0-$\overline{B}_s^0$ mixing frequency with $B_s^0 \to D_s^\mp h^\pm \pi^\pm \pi^\mp$ decays

LHCb collaboration†

Abstract

The CKM angle γ is measured for the first time from mixing-induced CP violation between $B_s^0 \to D_s^\mp K^\pm \pi^\pm \pi^\mp$ and $\overline{B}_s^0 \to D_s^\pm K^\mp \pi^\mp \pi^\pm$ decays reconstructed in proton-proton collision data corresponding to an integrated luminosity of 9 fb^{-1} recorded with the LHCb detector. A time-dependent amplitude analysis is performed to extract the CP-violating weak phase $\gamma - 2\beta_s$ and, subsequently, γ by taking the B_s^0–$\overline{B}_s^0$ mixing phase β_s as an external input. The measurement yields $\gamma = (44 \pm 12)°$ modulo 180°, where statistical and systematic uncertainties are combined. An alternative model-independent measurement, integrating over the five-dimensional phase space of the decay, yields $\gamma = (44^{+20}_{-13})°$ modulo 180°. Moreover, the B_s^0–$\overline{B}_s^0$ oscillation frequency is measured from the flavour-specific control channel $B_s^0 \to D_s^- \pi^+\pi^+\pi^-$ to be $\Delta m_s = (17.757 \pm 0.007\,(\text{stat}) \pm 0.008\,(\text{syst}))\,\text{ps}^{-1}$, consistent with and more precise than the current world-average value.

Published in JHEP 03 (2021) 137

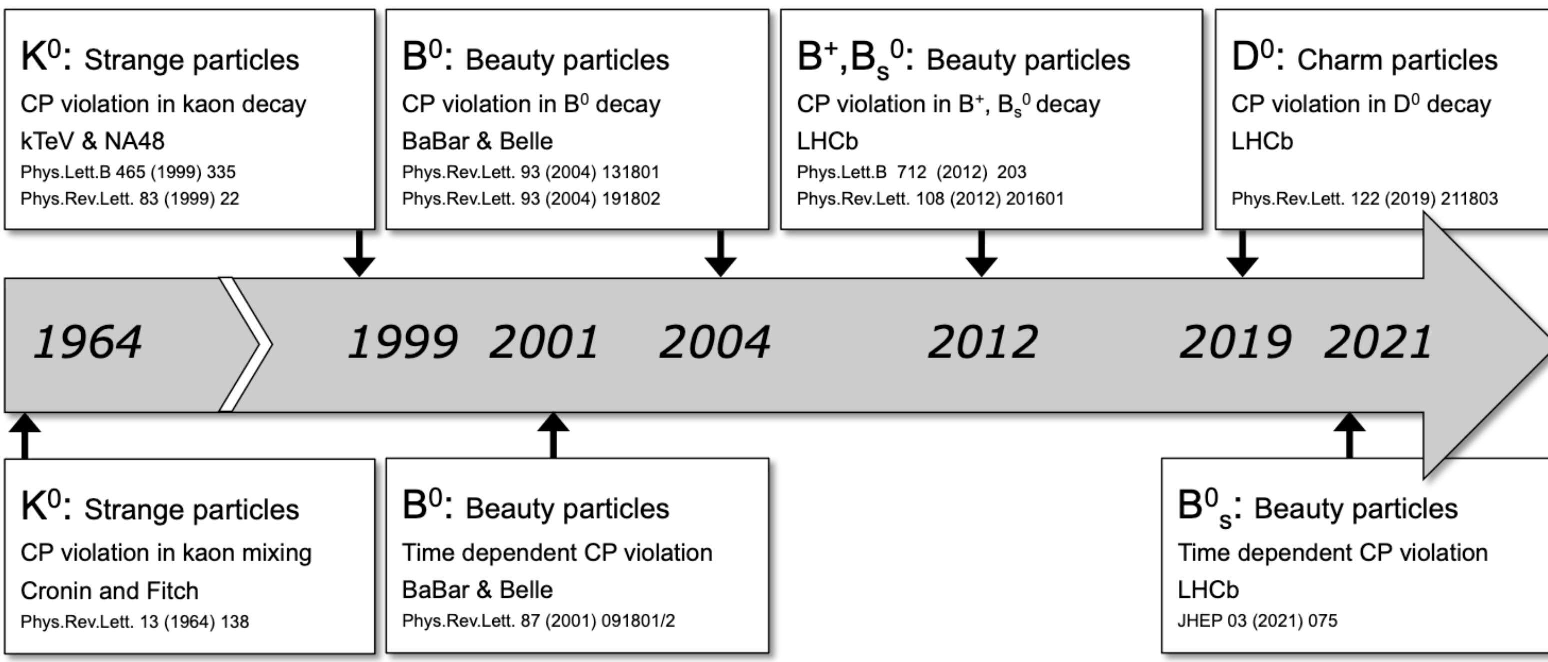
© 2021 CERN for the benefit of the LHCb collaboration. CC BY 4.0 licence

†Authors are listed at the end of this paper.

Measurements presented today are the (only) input to the LHCb B_s combination!

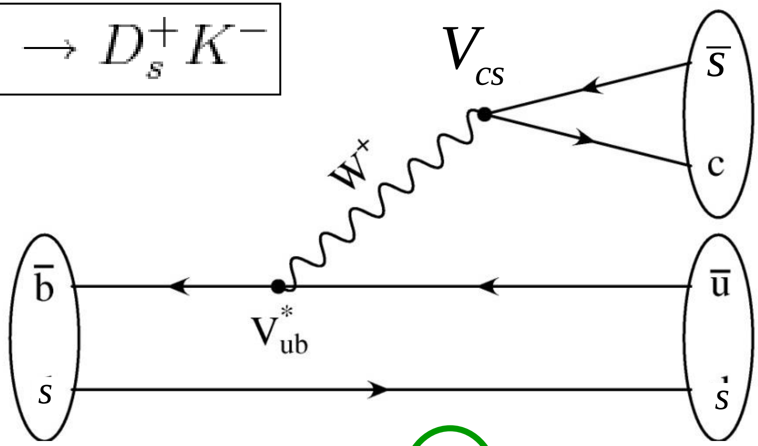
History

- 2021: First Time dependent CP violation in $B^0_s\,(\rightarrow K^+K^-)$



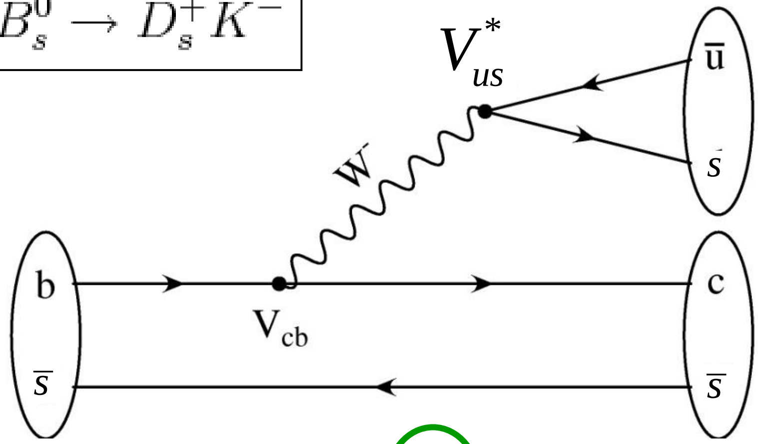
CP Violation in Interference between Mixing and Decay

$B_s^0 \to D_s^+ K^-$



$V_{ub}^* V_{cs} \propto \lambda^3 e^{i\gamma}$

$\bar{B}_s^0 \to D_s^+ K^-$



$V_{cb} V_{us}^* \propto \lambda^3$

$$\frac{A_{D_s^- K^+}}{\bar{A}_{D_s^- K^+}} = \frac{|A_{D_s^- K^+}|}{|\bar{A}_{D_s^- K^+}|} e^{i(\delta_s - \gamma)}$$

Similar size of amplitudes

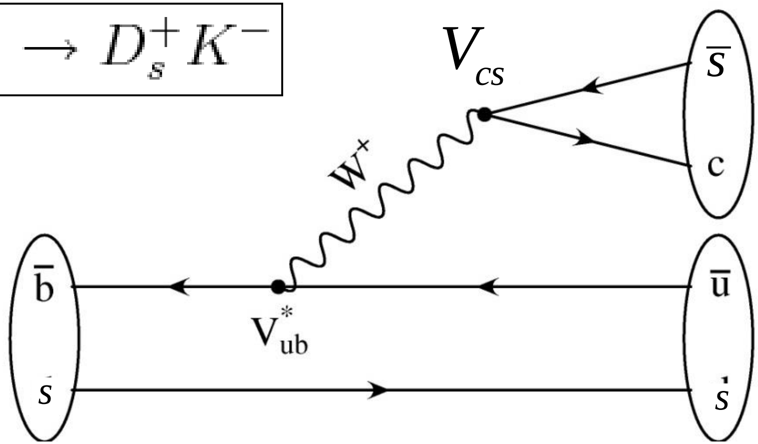
→ large interference

→ large sensitivty to phases

δ_s: strong phase difference

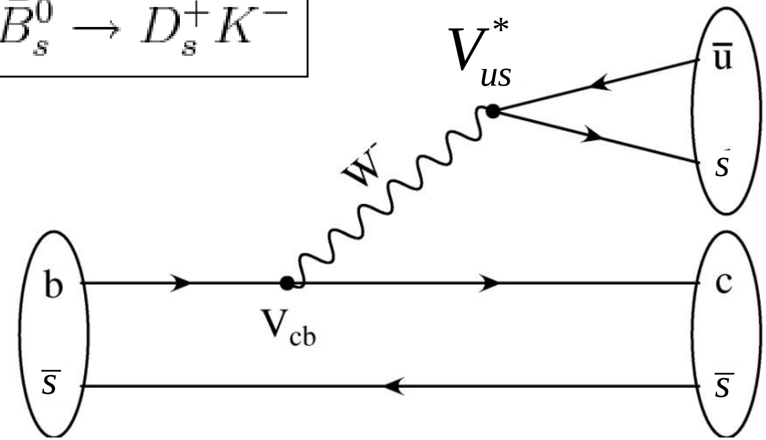
CP Violation in Interference between Mixing and Decay

$B_s^0 \to D_s^+ K^-$



$$V^*_{ub} V_{cs} \propto \lambda^3 e^{i\gamma}$$

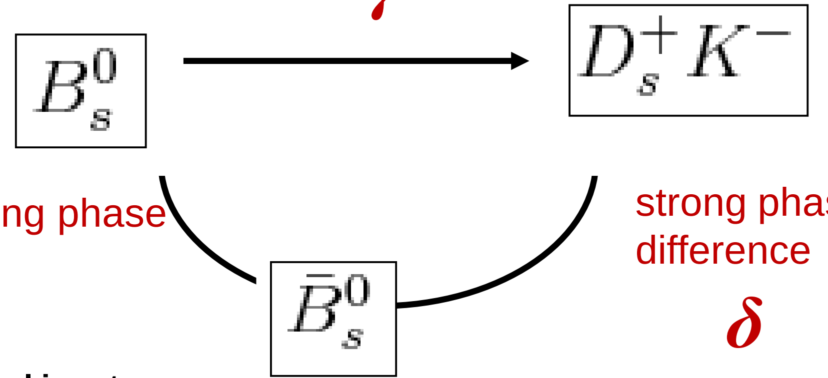
$\bar{B}_s^0 \to D_s^+ K^-$



$$V_{cb} V^*_{us} \propto \lambda^3$$

CKM phase

$-\gamma$



weak mixing phase

ϕ_s

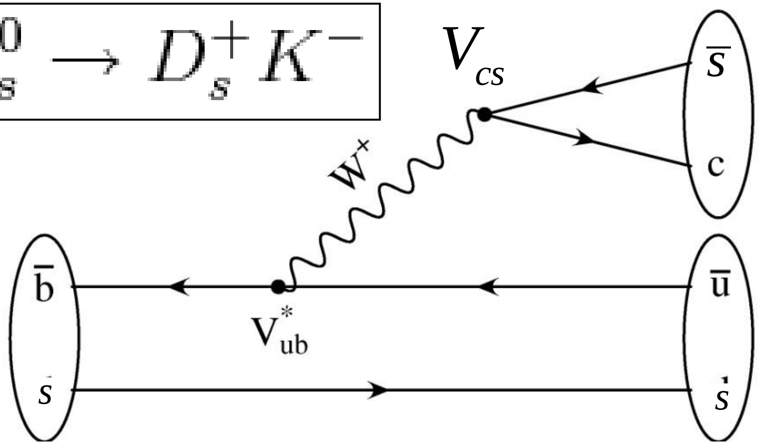
(from external input in this analysis)

strong phase difference

δ

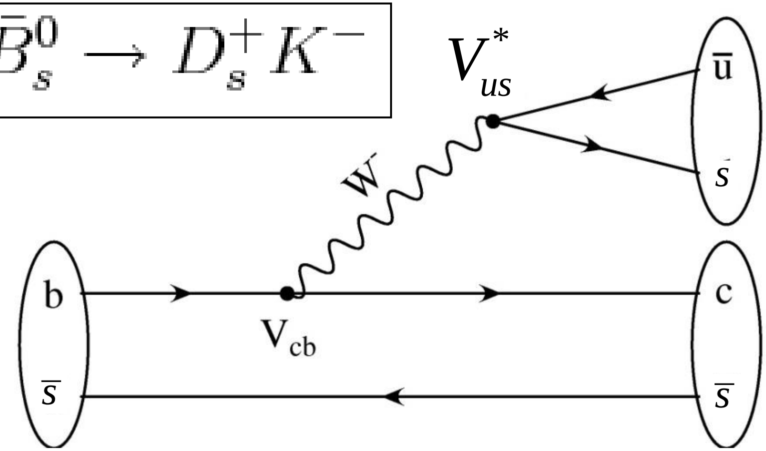
CP Violation in Interference between Mixing and Decay

$$B_s^0 \to D_s^+ K^-$$

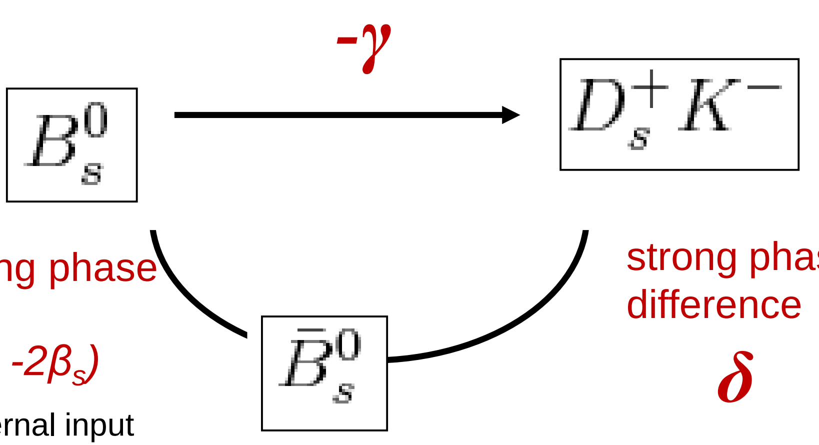


$$V_{ub}^* V_{cs} \propto \lambda^3 e^{i\gamma}$$

$$\bar{B}_s^0 \to D_s^+ K^-$$



$$V_{cb} V_{us}^* \propto \lambda^3$$



weak mixing phase

ϕ_s (~ $-2\beta_s$)

(from external input in this analysis)

strong phase difference

δ

$$\left|\lambda_f\right| = \left|\frac{q}{p}\frac{\bar{A}_f}{A_f}\right| \neq 1$$

CPV in mixing small (experimental compatible with 0)

CPV in decay small

However, CPV in interference between mixing and decay sizeable.

Time Dependent Decay Rates

$$\frac{d\Gamma_{B_s^0\to f}(t)}{dt} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f\cos(\Delta m_s t) - S_f\sin(\Delta m_s t)\right],$$

$$\frac{d\Gamma_{\bar{B}_s^0\to f}(t)}{dt} = \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f\cos(\Delta m_s t) + S_f\sin(\Delta m_s t)\right],$$

Assuming no CPV in mixing and no CPV in decay

$$C_f = \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2} = -C_{\bar{f}} = -\frac{1-|\lambda_{\bar{f}}|^2}{1+|\lambda_{\bar{f}}|^2}$$

$$S_f = \frac{2\mathcal{I}m(\lambda_f)}{1+|\lambda_f|^2}, \quad A_f^{\Delta\Gamma} = \frac{-2\mathcal{R}e(\lambda_f)}{1+|\lambda_f|^2}$$

$$S_{\bar{f}} = \frac{2\mathcal{I}m(\lambda_{\bar{f}})}{1+|\lambda_{\bar{f}}|^2}, \quad A_{\bar{f}}^{\Delta\Gamma} = \frac{-2\mathcal{R}e(\lambda_{\bar{f}})}{1+|\lambda_{\bar{f}}|^2}$$

Need flavor tagging and need to resolve fast mixing to access C_f and S_f

f: $D_s^+K^-$

$\bar{f}$: $D_s^-K^+$

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f}$$

$A_f^{\Delta\Gamma}$, S_f & C_f $\longrightarrow$ r_{DsK}, γ & δ

$$\frac{\mathrm{d}\Gamma_{B_s^0\to f}(t)}{\mathrm{d}t} = \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f\cos(\Delta m_s t) - S_f\sin(\Delta m_s t)\right],$$

$$\frac{\mathrm{d}\Gamma_{\bar{B}_s^0\to f}(t)}{\mathrm{d}t} = \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f\cos(\Delta m_s t) + S_f\sin(\Delta m_s t)\right],$$

$$C_f = \frac{1-r_{D_sK}^2}{1+r_{D_sK}^2},$$

$$A_f^{\Delta\Gamma} = \frac{-2r_{D_sK}\cos(\delta-(\gamma-2\beta_s))}{1+r_{D_sK}^2}, \quad A_{\bar{f}}^{\Delta\Gamma} = \frac{-2r_{D_sK}\cos(\delta+(\gamma-2\beta_s))}{1+r_{D_sK}^2},$$

$$S_f = \frac{2r_{D_sK}\sin(\delta-(\gamma-2\beta_s))}{1+r_{D_sK}^2}, \quad S_{\bar{f}} = \frac{-2r_{D_sK}\sin(\delta+(\gamma-2\beta_s))}{1+r_{D_sK}^2}.$$

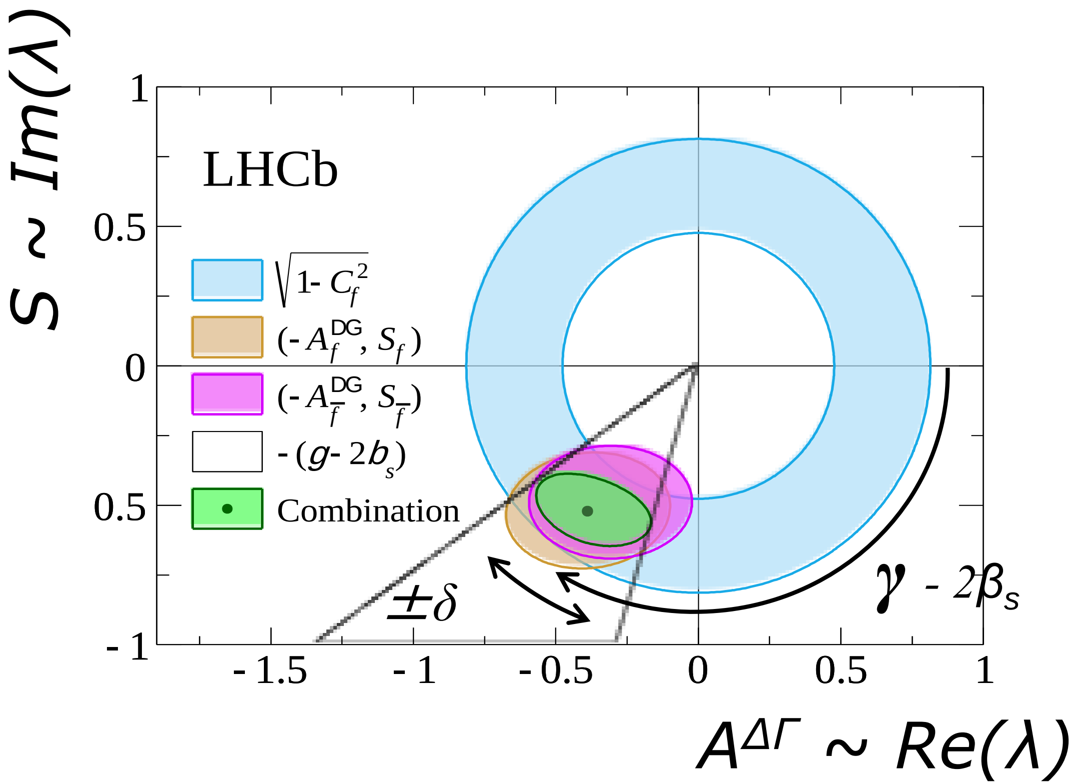
$$r_{D_sK} \equiv |\lambda_{D_sK}| = |A(\overline{B}_s^0 \to D_s^- K^+)/A(B_s^0 \to D_s^- K^+)|$$

Need to measure decays to $D_s^+K^-$ and $D_s^-K^+$ to disentangle γ and δ.

$A_f^{\Delta\Gamma}$, S_f & C_f → r_{DsK}, γ & δ

- Polar: |λ| and γ
- Cartesian: $A^{\Delta\Gamma}$ and S

$$S_f = \frac{2\mathcal{I}m(\lambda_f)}{1+|\lambda_f|^2}\,, \quad A_f^{\Delta\Gamma} = \frac{-2\mathcal{R}e(\lambda_f)}{1+|\lambda_f|^2}$$



A note on conventions:

1) We use: $\Delta\Gamma_s = \Gamma_L - \Gamma_H > 0$

2) Opposite convention is equivalent if at the same time $A^{\Delta\Gamma} \rightarrow -A^{\Delta\Gamma}$

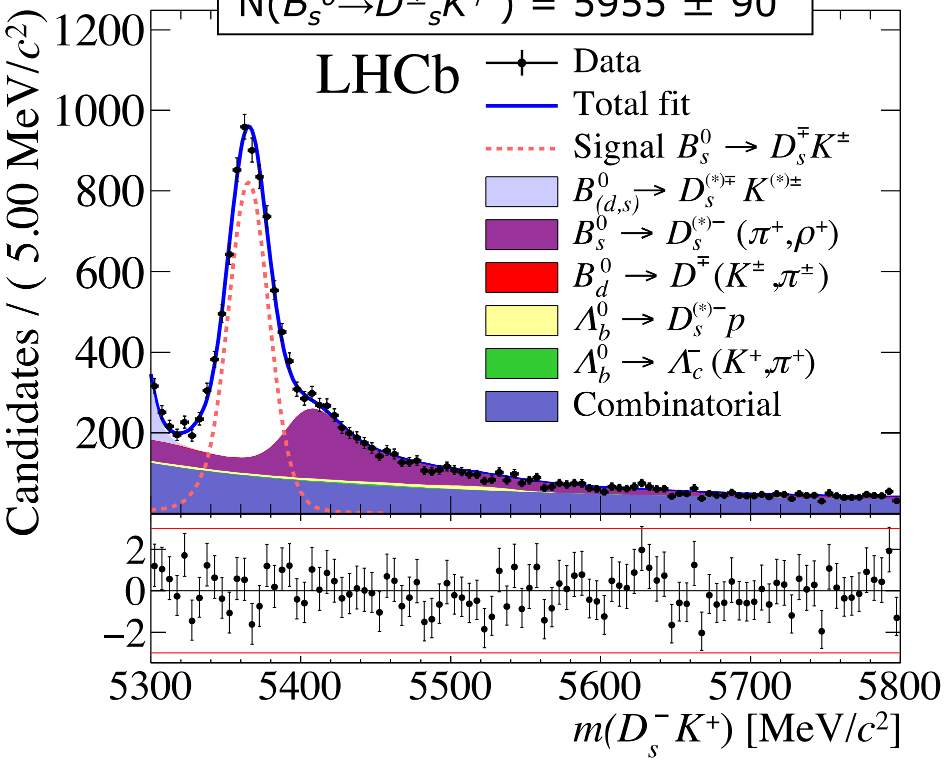
$B_s^0 \to D_s^\pm K^\mp$ Analysis

- obtain B_s^0 signal sample: 3D fit to m_{Bs}, m_{Ds}, particle identification
- B_s^0 or $\overline{B}_s^0$: flavour tagging
- decay time: resolution & acceptance
- result: decay time fit

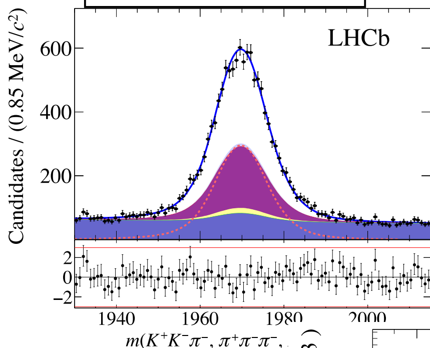
$B_s^0 \to D_s^{\pm} K^{\mp}$ Analysis: mass fit

- Need to (statistically) separate signal from background
- Backgrounds:
  - Combinatorial
  - Partially reconstructed background ($B_s^0 \to D^*_s K^{\mp}$, etc)
  - Misidentified background ($B_s^0 \to D^{\pm}_s \pi^{\mp}$)

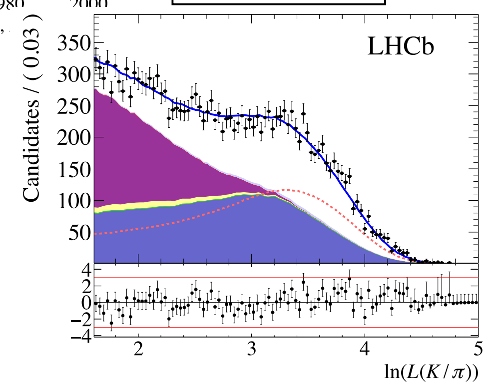
N($B_s^0 \to D^{\pm}_s K^{\mp}$) = 5955 ± 90



Comb. vs true D_s:

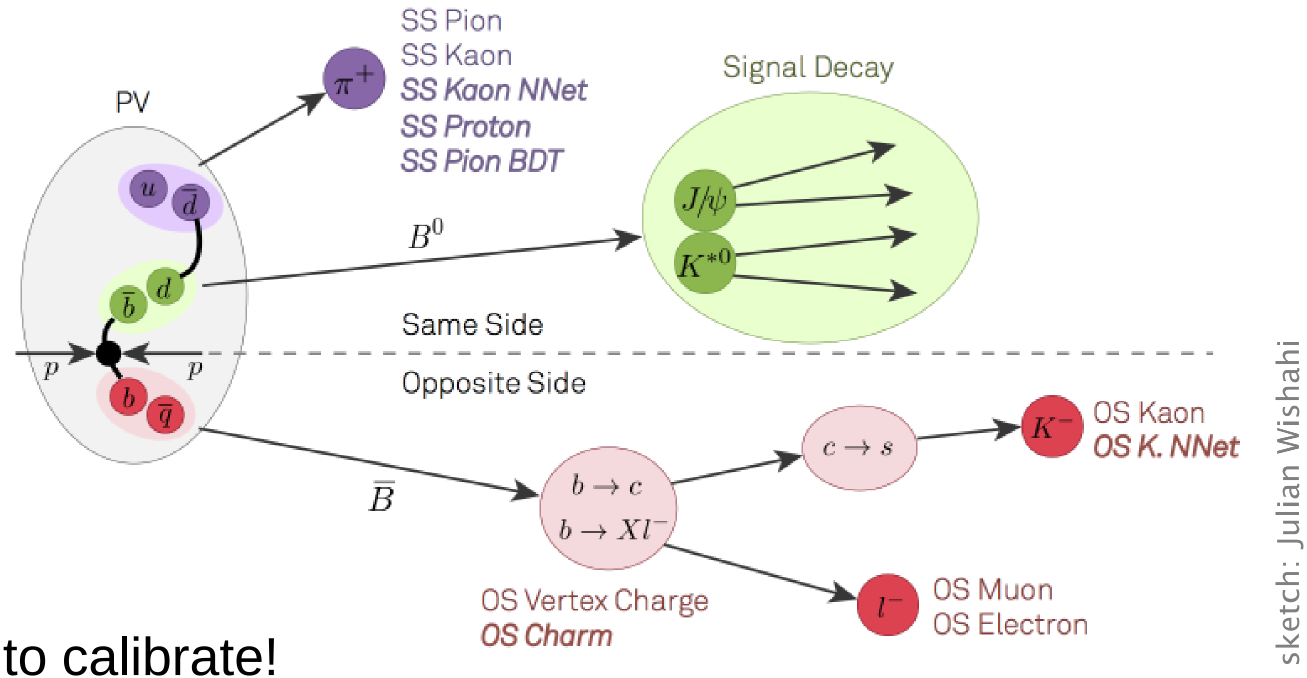


$D_s\pi$ vs D_sK:



$B_s^0 \to D_s^{\pm} K^{\mp}$ Analysis: Flavour Tagging

- B_s^0 or $\overline{B_s^0}$:



- Use $B_s^0 \to D_s^+ \pi^-$ to calibrate!

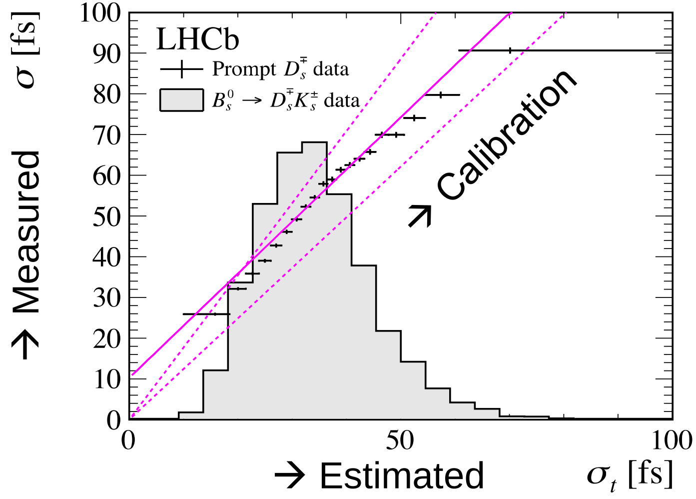
$B_s^0 \to D_s^- \pi^+$	ε_{tag} [%]	ε_{eff} [%]
OS only	12.94 ± 0.11	1.41 ± 0.11
SS only	39.70 ± 0.16	1.29 ± 0.13
Both OS and SS	24.21 ± 0.14	3.10 ± 0.18
Total	76.85 ± 0.24	5.80 ± 0.25

effective statistical size of the sample

$B_s^0 \to D^{\pm}_s K^{\mp}$ Analysis: Decay Time

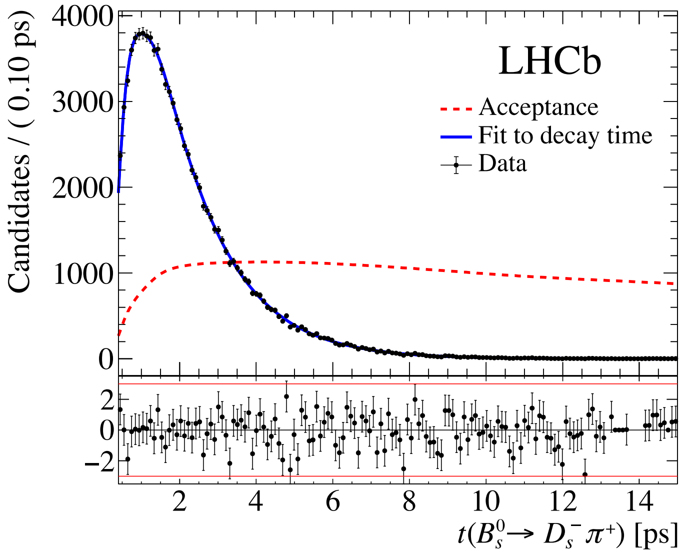
- Resolution

(use prompt D^+_s calibrate)



- Acceptance

(use $B_s^0 \to D^+_s \pi^-$ to calibrate)



$B_s^0 \to D_s^\pm K^\mp$ Analysis: Fit Result

- Decay time fit:

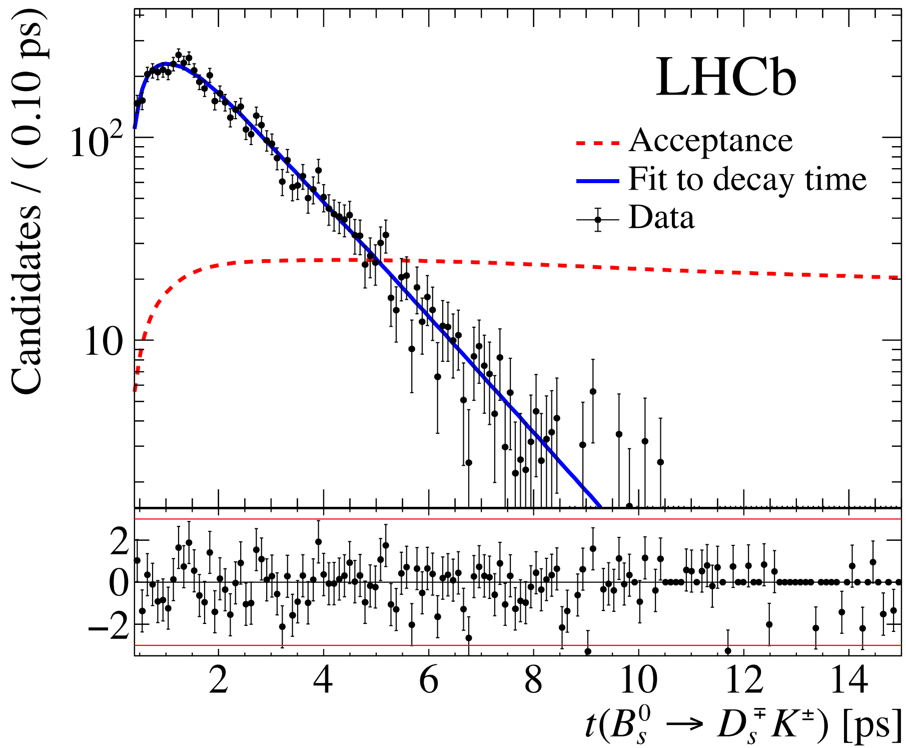
  fix some parameters

$$
\begin{aligned}
\Delta m_s &= (17.757 \pm 0.021)\ \mathrm{ps}^{-1}\,,\\
\Gamma_s &= (0.6643 \pm 0.0020)\ \mathrm{ps}^{-1}\,,\\
\Delta\Gamma_s &= (0.083 \pm 0.006)\ \mathrm{ps}^{-1}\,,\\
\rho(\Gamma_s, \Delta\Gamma_s) &= -0.239\,,\\
A_{\mathrm{prod}} &= (1.1 \pm 2.7)\%,\\
A_{\mathrm{det}} &= (1 \pm 1)\%
\end{aligned}
$$

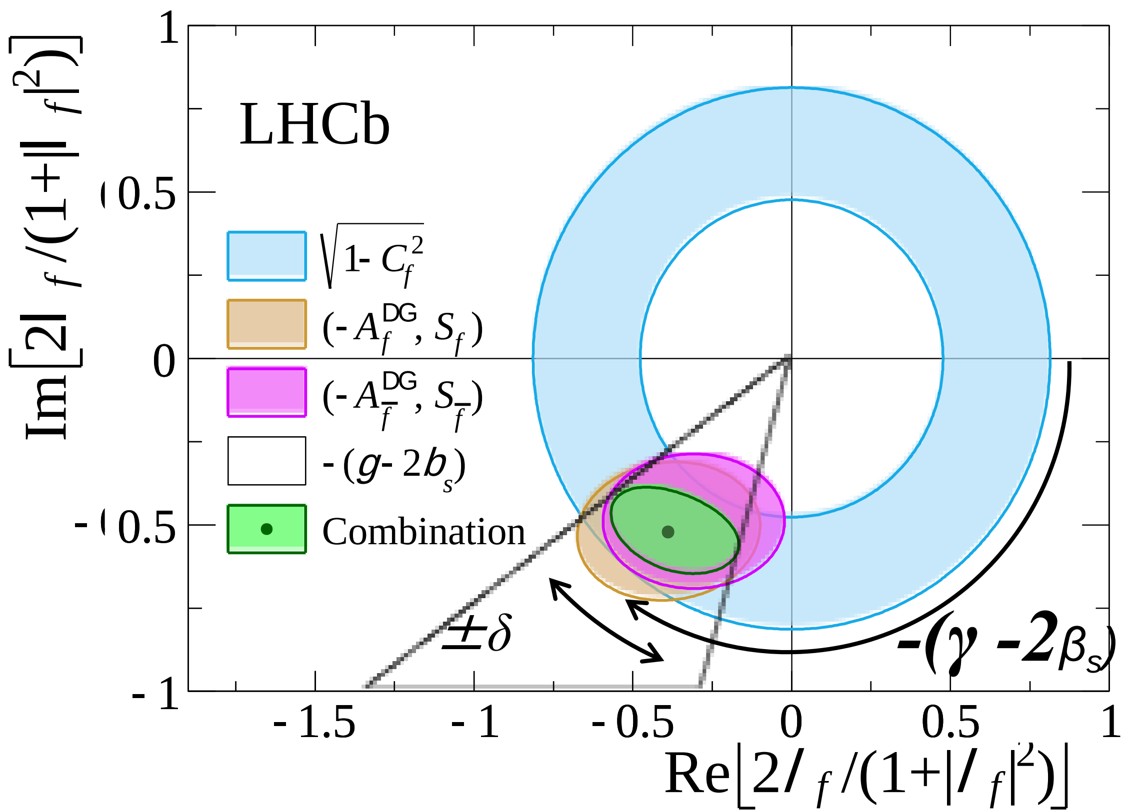
$$
\begin{aligned}
\frac{\mathrm{d}\Gamma_{B_s^0\to f}(t)}{\mathrm{d}t} &= \frac{1}{2}|A_f|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right.\\
&\left. + C_f\cos(\Delta m_s t) - S_f\sin(\Delta m_s t)\right],\\
\frac{\mathrm{d}\Gamma_{\bar{B}_s^0\to f}(t)}{\mathrm{d}t} &= \frac{1}{2}|A_f|^2\left|\frac{p}{q}\right|^2(1+|\lambda_f|^2)e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right.\\
&\left. - C_f\cos(\Delta m_s t) + S_f\sin(\Delta m_s t)\right],
\end{aligned}
$$

Parameter	Value
C_f	$0.730 \pm 0.142 \pm 0.045$
$A_f^{\Delta\Gamma}$	$0.387 \pm 0.277 \pm 0.153$
$A_{\bar{f}}^{\Delta\Gamma}$	$0.308 \pm 0.275 \pm 0.152$
S_f	$-0.519 \pm 0.202 \pm 0.070$
$S_{\bar{f}}$	$-0.489 \pm 0.196 \pm 0.068$

analysis statistical limited



$B_s^0 \to D_s^{\pm} K^{\mp}$ Analysis: Result



$$\gamma = (128\,^{+17}_{-22})^\circ$$

$$\delta = (358\,^{+13}_{-14})^\circ$$

$$r_{D_sK} = 0.37\,^{+0.10}_{-0.09}$$

$B_s^0 \to D_s^{\pm} K^{\mp} \pi^+ \pi^-$ Analysis

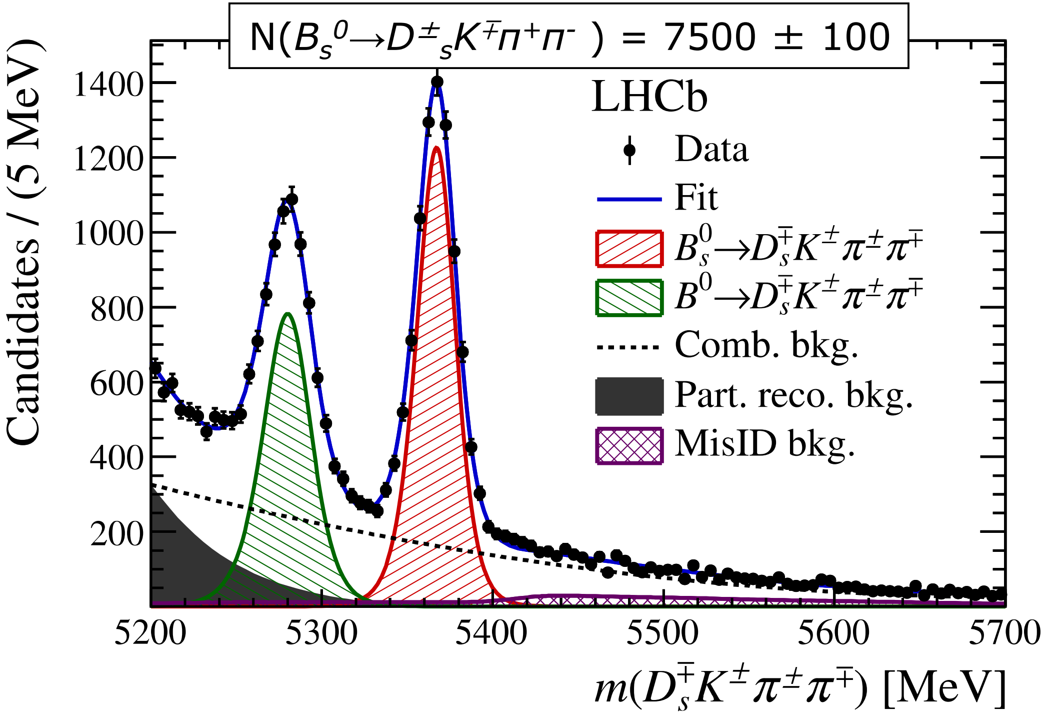
Conceptually identical to the $B_s^0 \to D_s^{\pm} K^{\mp}$ analysis

- obtain B_s^0 signal sample: 3D fit to m_{Bs}, m_{Ds}, particle identification
- B_s^0 or $\overline{B}_s^0$: flavour tagging
- decay time: resolution & acceptance
- result: decay time fit

+ amplitude analysis

$B_s^0 \to D^{\pm}_s K^{\mp} \pi^+\pi^-$ Analysis: mass fit

- Need to (statistically) separate signal from background
- Backgrounds:
  - Combinatorial
  - Partially reconstructed background ($B_s^0 \to D^*_s K^{\mp}$, etc)
  - Misidentified background ($B_s^0 \to D^{\pm}_s \pi^{\mp}$)



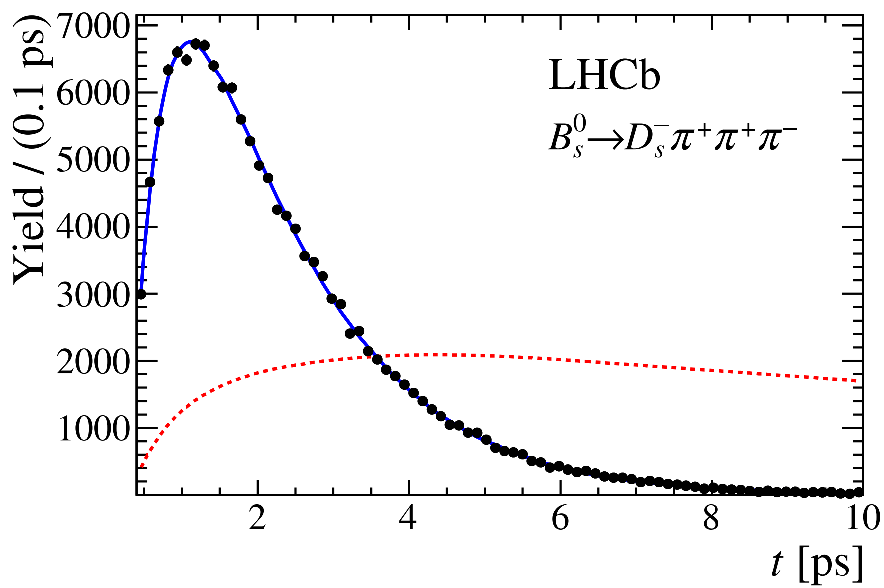
$B_s^0 \to D_s^{\pm} K^{\mp} \pi^+ \pi^-$ Analysis

- Flavour Tagging

(b) Run 2 data.

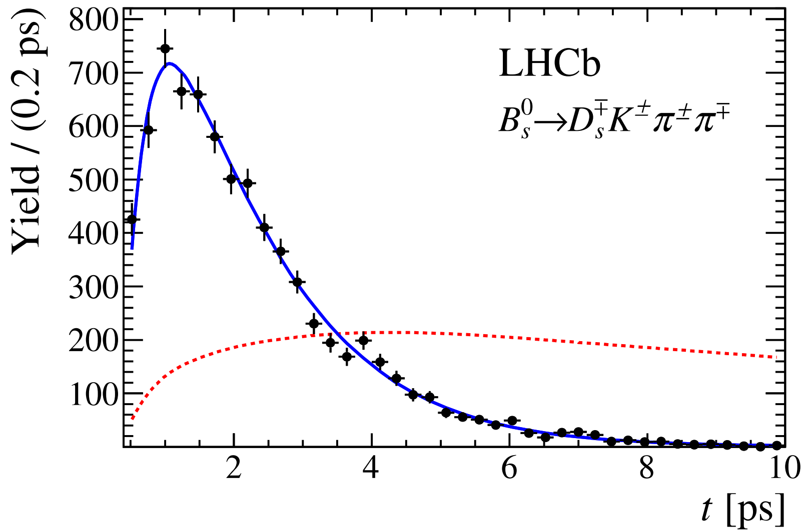
	$\epsilon_{tag}[\%]$	$\langle\omega\rangle[\%]$	$\epsilon_{eff}[\%]$
Only OS	11.91 ± 0.04	37.33 ± 0.41	1.11 ± 0.05
Only SS	40.95 ± 0.08	42.41 ± 0.29	1.81 ± 0.10
Both OS-SS	28.96 ± 0.12	35.51 ± 0.32	3.61 ± 0.13
Combined	81.82 ± 0.15	39.23 ± 0.32	6.52 ± 0.17

- Decay time acceptance



$B_s^0 \to D_s^{\pm} K^{\mp} \pi^+ \pi^-$: Decay Time Fit

Fit parameter	Value
C_f	$0.631 \pm 0.096 \pm 0.032$
$A_f^{\Delta\Gamma}$	$-0.334 \pm 0.232 \pm 0.097$
$A_{\bar{f}}^{\Delta\Gamma}$	$-0.695 \pm 0.215 \pm 0.081$
S_f	$-0.424 \pm 0.135 \pm 0.033$
$S_{\bar{f}}$	$-0.463 \pm 0.134 \pm 0.031$



Parameter	Model-independent
r	$0.47\,^{+0.08}_{-0.08}\,^{+0.02}_{-0.03}$
κ	$0.88\,^{+0.12}_{-0.19}\,^{+0.04}_{-0.07}$
δ [°]	$-6\,^{+10}_{-12}\,^{+2}_{-4}$
$\gamma - 2\beta_s$ [°]	$42\,^{+19}_{-13}\,^{+6}_{-2}$

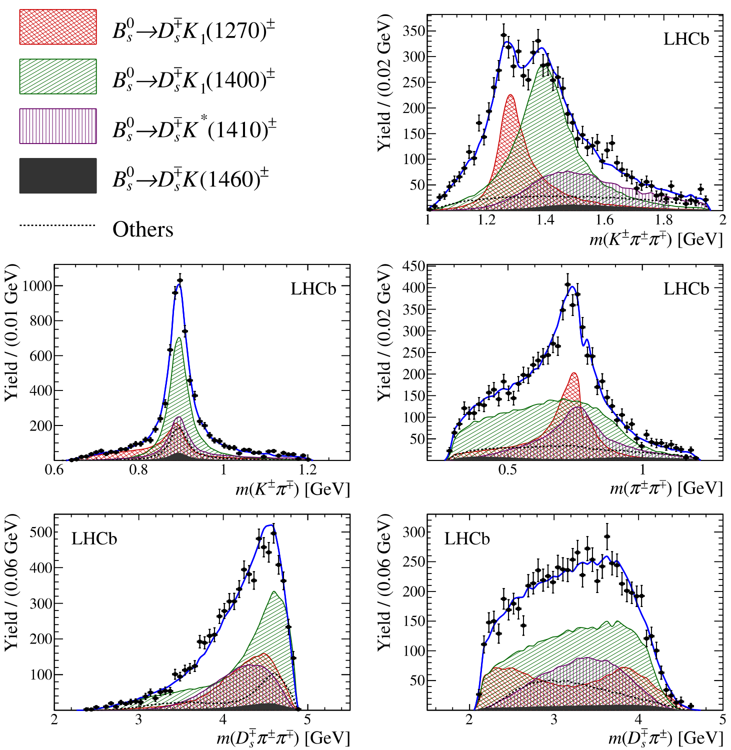
coherence factor integrated over the entire phase space

$B_s^0 \to D_s^{\pm} K^{\mp} \pi^+\pi^-$: Amplitude Analysis

- Let's take it one step further:

time-dependent amplitude fit

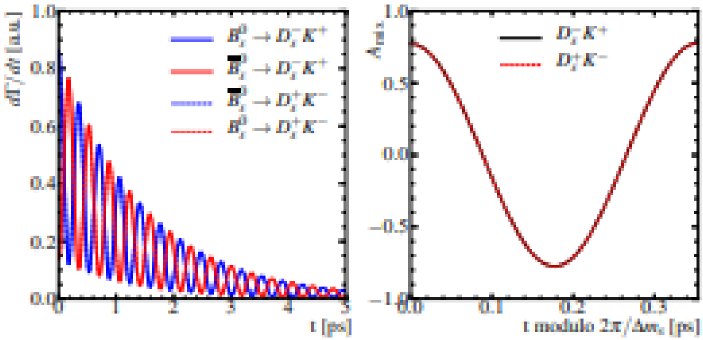
Decay channel	$F_i^c[\%]$	$F_i^u[\%]$
$B_s^0 \to D_s^{\mp}\,(K_1(1270)^{\pm} \to K^*(892)^0\,\pi^{\pm})$	$13.0 \pm 2.4 \pm 2.7 \pm 3.4$	$4.1 \pm 2.2 \pm 2.9 \pm 2.6$
$B_s^0 \to D_s^{\mp}\,(K_1(1270)^{\pm} \to K^{\pm}\,\rho(770)^0)$	$16.0 \pm 1.4 \pm 1.8 \pm 2.1$	$5.1 \pm 2.2 \pm 3.5 \pm 2.0$
$B_s^0 \to D_s^{\mp}\,(K_1(1270)^{\pm} \to K_0^*(1430)^0\,\pi^{\pm})$	$3.4 \pm 0.5 \pm 1.0 \pm 0.4$	$1.1 \pm 0.5 \pm 0.6 \pm 0.5$
$B_s^0 \to D_s^{\mp}\,(K_1(1400)^{\pm} \to K^*(892)^0\,\pi^{\pm})$	$63.9 \pm 5.1 \pm 7.4 \pm 13.5$	$19.3 \pm 5.2 \pm 8.3 \pm 7.8$
$B_s^0 \to D_s^{\mp}\,(K^*(1410)^{\pm} \to K^*(892)^0\,\pi^{\pm})$	$12.8 \pm 0.8 \pm 1.5 \pm 3.2$	$12.6 \pm 2.0 \pm 2.6 \pm 4.1$
$B_s^0 \to D_s^{\mp}\,(K^*(1410)^{\pm} \to K^{\pm}\,\rho(770)^0)$	$5.6 \pm 0.4 \pm 0.6 \pm 0.7$	$5.6 \pm 1.0 \pm 1.2 \pm 1.8$
$B_s^0 \to D_s^{\mp}\,(K(1460)^{\pm} \to K^*(892)^0\,\pi^{\pm})$		$11.9 \pm 2.5 \pm 2.9 \pm 3.1$
$B_s^0 \to (D_s^{\mp}\,\pi^{\pm})_P\;K^*(892)^0$	$10.2 \pm 1.6 \pm 1.8 \pm 4.5$	$28.4 \pm 5.6 \pm 6.4 \pm 15.3$
$B_s^0 \to (D_s^{\mp}\,K^{\pm})_P\;\rho(770)^0$	$0.9 \pm 0.4 \pm 0.5 \pm 1.0$	
Sum	$125.7 \pm 6.4 \pm 6.9 \pm 19.9$	$88.1 \pm 7.0 \pm 10.0 \pm 20.9$



Parameter	Model-independent	Model-dependent
r	$0.47\,^{+0.08}_{-0.08}\,^{+0.02}_{-0.03}$	$0.56 \pm 0.05 \pm 0.04 \pm 0.07$
κ	$0.88\,^{+0.12}_{-0.19}\,^{+0.04}_{-0.07}$	$0.72 \pm 0.04 \pm 0.06 \pm 0.04$
δ [°]	$-6\,^{+10}_{-12}\,^{+2}_{-4}$	$-14 \pm 10 \pm 4 \pm 5$
$\gamma - 2\beta_s$ [°]	$42\,^{+19}_{-13}\,^{+6}_{-2}$	$42 \pm 10 \pm 4 \pm 5$

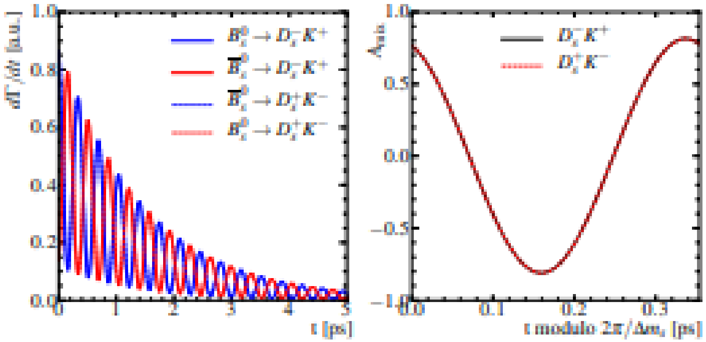
gain in precision of γ

Comparison: $B_s^0 \to D_s^\pm K^\mp \pi^+\pi^-$ versus $B_s^0 \to D_s^\pm K^\mp$



(a) Effect of interference for $r = 0.4$, $\delta = 0$, $\gamma = 0$.

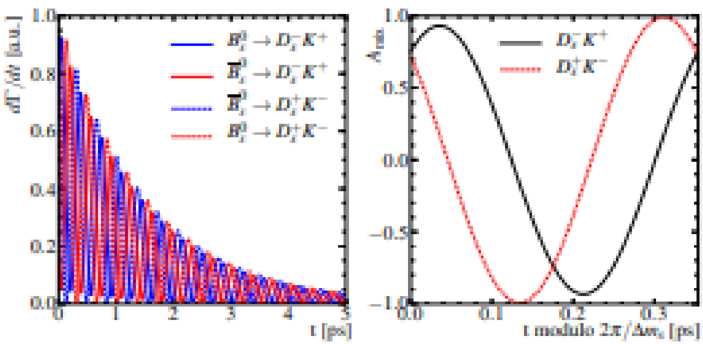
δ=0, γ=0



(b) Effect of the strong phase difference $r = 0.4$, $\delta = 20°$, $\gamma = 0$.

δ=20, γ=0

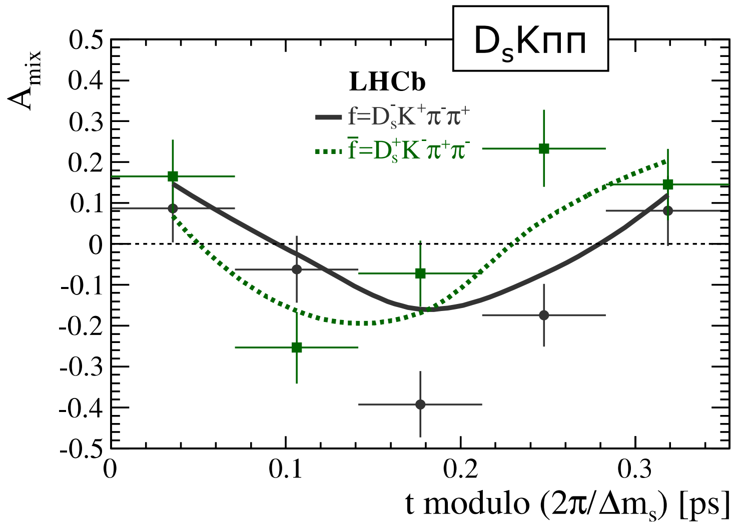
Need strong and weak phase difference to get CPV in Interference of mixing and decay



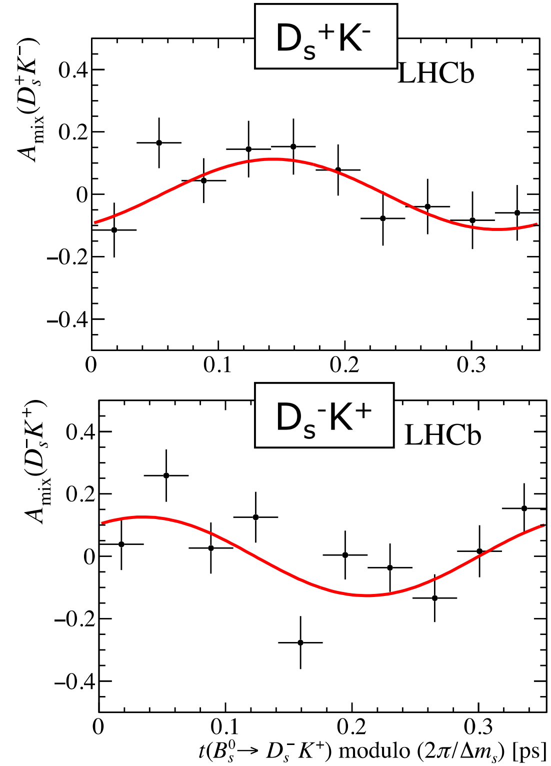
δ=20, γ=70

Quantum oscillations of neutral particles with the beauty quark / Veronesi, Michele CERN-THESIS-2021-193

Comparison: $B_s^0 \to D_s^{\pm} K^{\mp} \pi^+ \pi^-$ versus $B_s^0 \to D_s^{\pm} K^{\mp}$



Parameter	Model-independent
r	$0.47\,^{+0.08}_{-0.08}\,^{+0.02}_{-0.03}$
κ	$0.88\,^{+0.12}_{-0.19}\,^{+0.04}_{-0.07}$
δ [°]	$-6\,^{+10}_{-12}\,^{+2}_{-4}$
$\gamma - 2\beta_s$ [°]	$42\,^{+19}_{-13}\,^{+6}_{-2}$



$$\gamma = (128\,^{+17}_{-22})^\circ$$

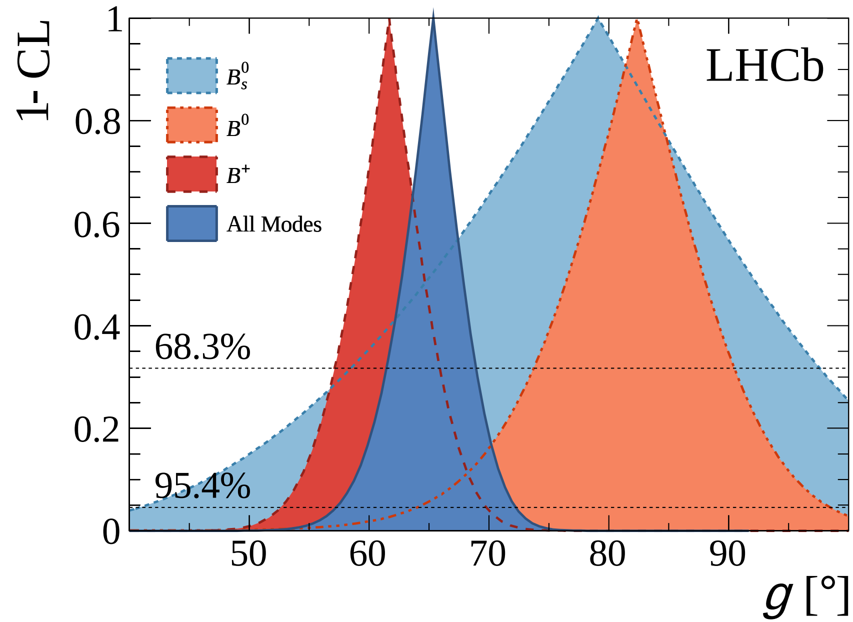
$$\delta = (358\,^{+13}_{-14})^\circ$$

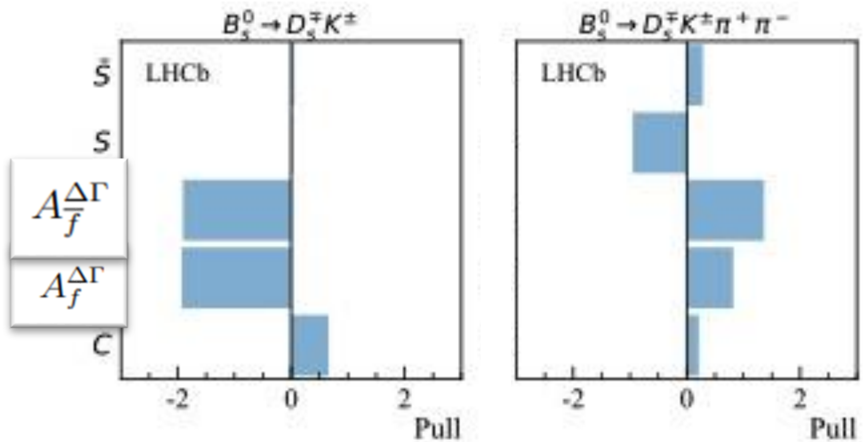
$$r_{D_sK} = 0.37\,^{+0.10}_{-0.09}$$

γ from $B_s^0 \to D_s^{\pm} K^{\mp} \pi^+ \pi^-$ and $B_s^0 \to D_s^{\pm} K^{\mp}$

- Contribution to γ average

	Measurement	χ^2	No. of obs.
Beauty sector	$B^{\pm} \to Dh^{\pm}, D \to h^{\pm}h'^{\mp}$	2.71	8
	$B^{\pm} \to Dh^{\pm}, D \to h^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$	7.36	8
	$B^{\pm} \to Dh^{\pm}, D \to h^{\pm}h'^{\mp}\pi^{0}$	7.14	11
	$B^{\pm} \to Dh^{\pm}, D \to K_S^0 h^{+}h^{-}$	4.67	6
	$B^{\pm} \to Dh^{\pm}, D \to K_S^0 K^{\pm}\pi^{\mp}$	7.57	7
	$B^{\pm} \to D^{*}h^{\pm}, D \to h^{\pm}h'^{\mp}$	7.31	16
	$B^{\pm} \to DK^{*\pm}, D \to h^{\pm}h'^{\mp}(\pi^{+}\pi^{-})$	3.71	12
	$B^{0} \to DK^{*0}, D \to h^{\pm}h'^{\mp}(\pi^{+}\pi^{-})$	9.45	12
	$B^{0} \to DK^{*0}, D \to K_S^0 h^{+}h^{-}$	3.26	4
	$B^{\pm} \to Dh^{\pm}\pi^{+}\pi^{-}, D \to h^{\pm}h'^{\mp}$	1.34	11
	$B_s^0 \to D_s^{\mp}K^{\pm}$	5.71	5
	$B_s^0 \to D_s^{\mp}K^{\pm}\pi^{+}\pi^{-}$	2.88	5
	$B^{0} \to D^{\mp}\pi^{\pm}$	0.00	2



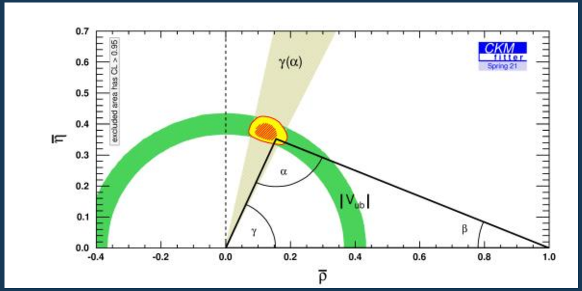


LHCb Coll., arXiv:2110.02350
"Simultaneous determination of CKM angle γ and charm mixing parameters"
JHEP 12 (2021) 141

Conclusions

- Precision measurements important to scrutinize the Standard Model
- Precision measurements reach very high mass scales
- Precision measurements are not yet precise enough

2021



2030 (Belle II 50ab^{-1},LHCb 50 fb^{-1})