Measurements of the CKM angle γ at LHCb

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On behalf of the **LHCb** collaboration

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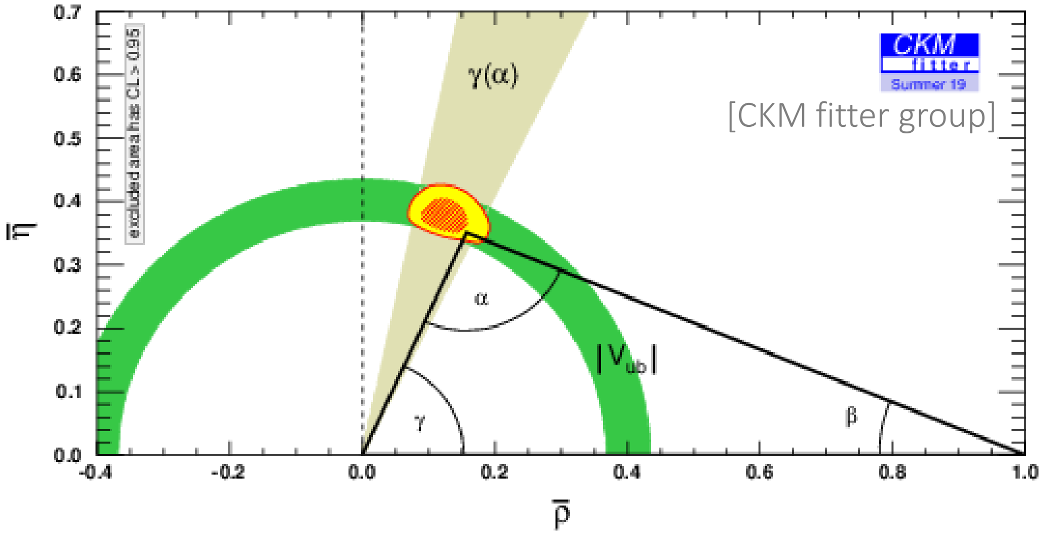
Introduction

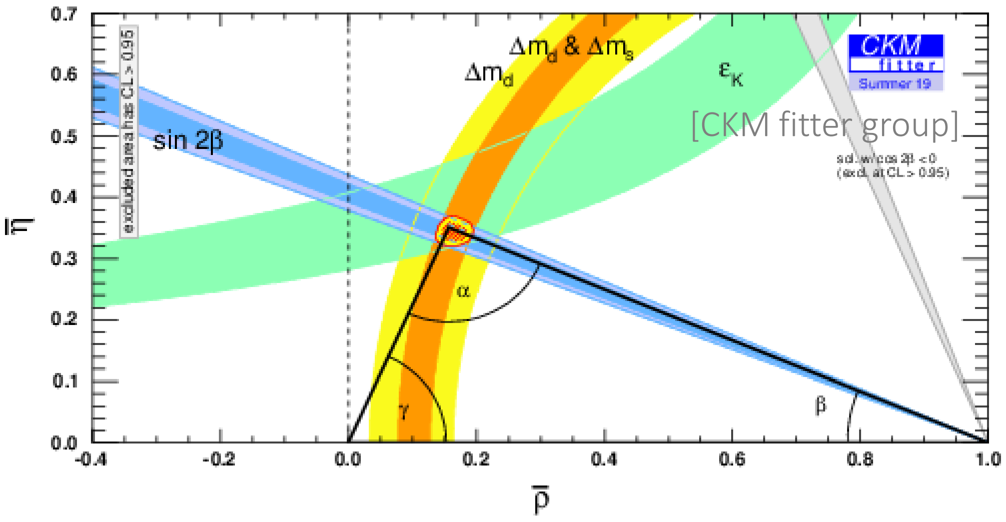
The angle γ is one of the angles of the CKM unitarity triangle:

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

Tree only measurements



Loop only measurements

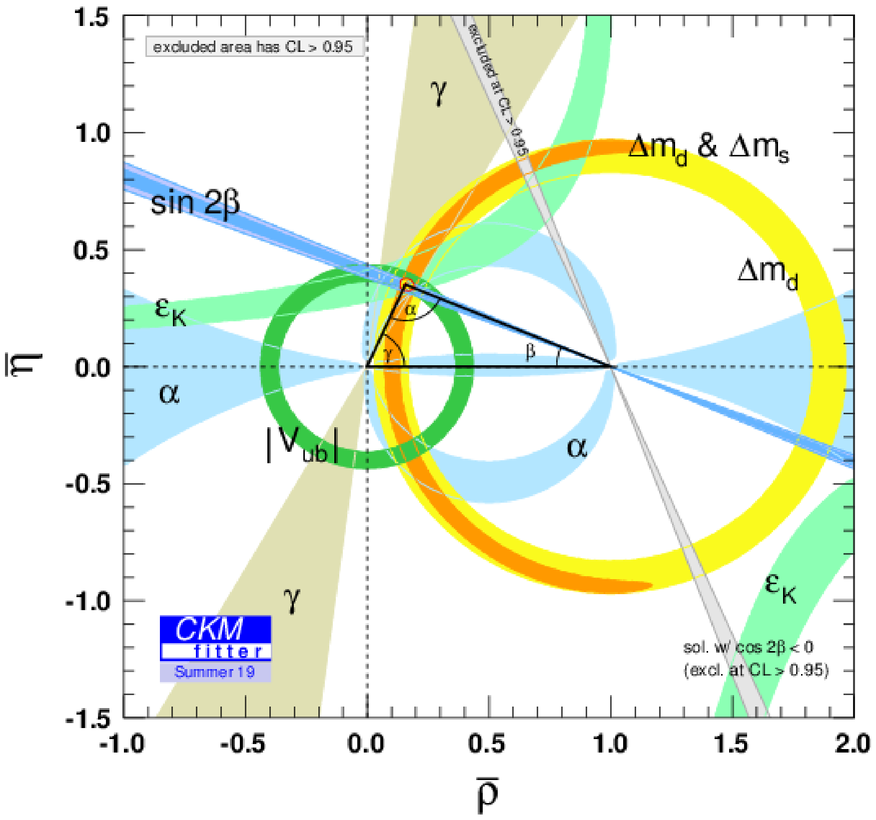


Introduction

The angle γ is one of the angles of the CKM unitarity triangle:

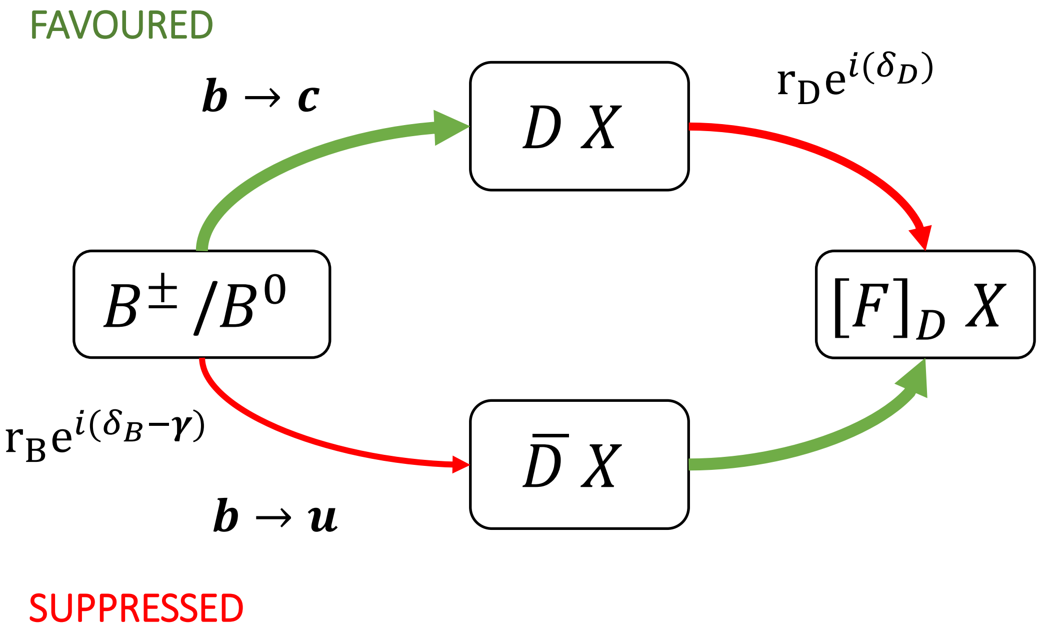
- It is studied in the heavy flavour physics experiments like LHCb, BELL, KEKB and BaBar.
- It is a Charge-Parity Violation (CPV) parameter.
- It can be measured from tree-level processes only and it is a standard candle measurement in the SM.
- Very small theoretical uncertainties associated with tree-level measurements: $\delta\gamma/\gamma = O(10^{-7})$. [JHEP 01 051]
- Discrepancy between tree-level and loop measurements can be used in probing the New Physics effects beyond the Standard Model.

[CKM fitter group]



$B \to DK$ decays

The CKM angle γ can be measured in processes where the interference between favoured quark transition $b \to c$ and suppressed $b \to u$ occurs.



	Method	X	$[F]_D$
$B^0/B^{\pm}$	ADS (mixed state)	K, π	$[K\pi, K\pi\pi\pi]$
$B^0/B^{\pm}$	GLW (CP eigenstate)	K, π	$[KK, \pi\pi, \pi\pi\pi\pi]$
$B^0/B^{\pm}$	GLS	K, π	$[hh]$
B^0	BPGGSZ	K^{*0}	$[K_S^0 hh]$
B^0/B_s^0	Time-Dependent	$K, K^{*\pm}, K^{*0}$	$[hhh, hh]$

$$r_B = \frac{A(B \to \bar{D}K)}{A(B \to DK)}$$

$$r_D = \frac{A(D \to FX)}{A(\bar{D} \to FX)}$$

$B \to DK$ decays

Several methods of measurements of the angle γ: GLW, ADS, Dalitz plots and time-dependent.

GLW [PL B253 1991 483]

$$A_{CP}=\frac{\Gamma(\bar{B}^0\to D_{CP}\bar{K}^{*0})-\Gamma(B^0\to D_{CP}K^{*0})}{\Gamma(\bar{B}^0\to D_{CP}\bar{K}^{*0})+\Gamma(B^0\to D_{CP}K^{*0})}$$

$$A_{CP}=\frac{2\kappa r_B^{DK^{*0}}\sin\left(\delta_B^{DK^{*0}}\right)\sin(\gamma)}{1+r_B^2\pm 2r_B\cos(\delta_B)\cos(\gamma)}$$

R_{CP}

$KK/\pi\pi$

ADS [PRL 78 1997 3257]

$$A_{CP}=\frac{\Gamma\left(\bar{B}^0\to D^0_{K^+\pi^-}\bar{K}^{*0}\right)-\Gamma\left(B^0\to D^0_{K^-\pi^+}K^{*0}\right)}{\Gamma\left(\bar{B}^0\to D^0_{K^+\pi^-}\bar{K}^{*0}\right)+\Gamma\left(B^0\to D^0_{K^-\pi^+}K^{*0}\right)}$$

$$A_{CP}=\frac{2\kappa r_B^{DK^{*0}}r_D^{K^{*0}}\sin\left(\delta_B^{K^{*0}}+\delta_D^{K\pi}\right)\sin(\gamma)}{(r_B^{DK^{*0}})^2+(r_D^{K\pi})^2+2\kappa r_B^{DK^{*0}}r_D^{K^{*0}}\cos\left(\delta_B^{DK^{*0}}+\delta_D^{K\pi}\right)\cos(\gamma)}$$

$\propto R_{CP}$

BPGGSZ [PRD 68 054018]

$$N_i^{\pm}=h_{\pm}\left[F_i+\left(x_{\pm}^2+y_{\pm}^2\right)F_{-i}+2\sqrt{F_iF_{-i}}\right]$$
$$(x_{\pm}c_i+y_{\pm}s_i)$$
$$x_{\pm}=r_B\cos(\delta_B\pm\gamma)$$
$$y_{\pm}=r_B\sin(\delta_B\pm\gamma)$$

Time-Dependent

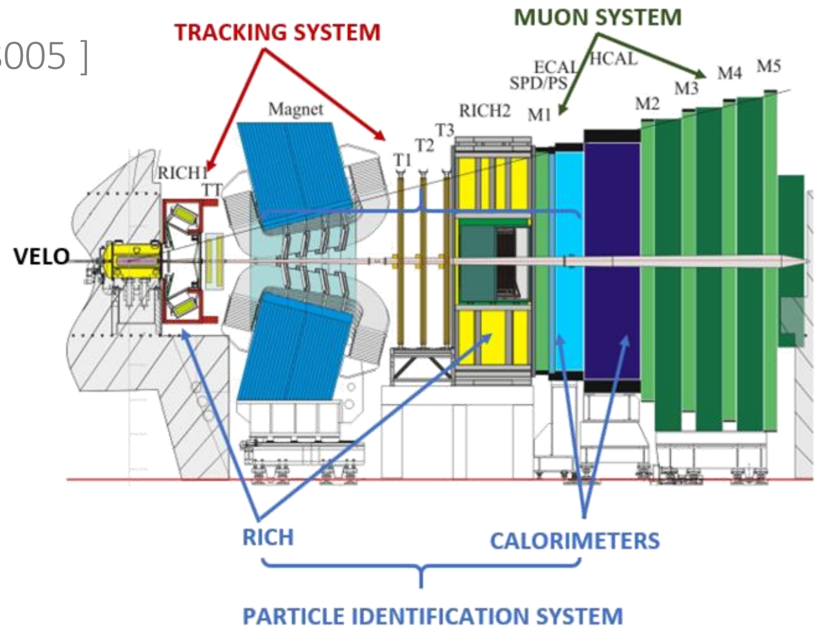
$$\frac{d\Gamma(x,t)}{e^{-\Gamma_s t}dt\,d\phi_4}$$
$$\propto\left(\left|A_f^c(x)\right|^2+r^2\left|A_f^u(x)\right|^2\right)\cosh\left(\frac{\Delta\Gamma_s t}{2}\right)$$
$$-2Re\left(A_f^c(x)^*r^2A_f^u(x)e^{i\delta-if(\gamma-2\beta_s)}\right)\sinh\left(\frac{\Delta\Gamma_s t}{2}\right)+\ \ldots$$

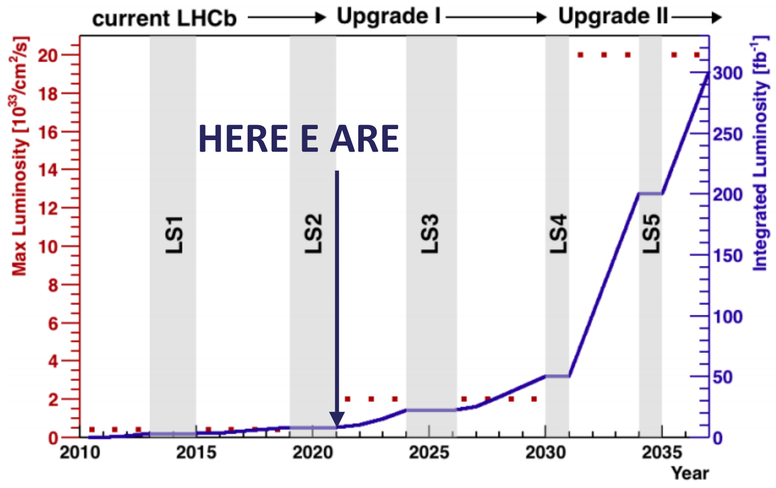
LHCb detector

LHCb spectrometer, which is designed to study heavy flavor physics of B mesons and C mesons:

- Covering the pseudorapidity range (2<η<5).
- Identification : ε_{h-h}~90% ε_{μ}~97%
- IP resolution : σ_{IP}=20 μm
- Momentum resolution: $\Delta p/p$=0.5–0.8 %
- Mass resolution : $\sigma(m_{B\to hh}) \approx 22\ MeV$
- Time resolution 45– 55 fs

[JINST 3 S08005]





Outline

Several **new** and updated results from 2020 and 2021:

- $\boldsymbol{B^0 \to DK^{*0}}$: the **new** D decay mode: $D \to K^-\pi^-\pi^+\pi^-$ analysis over Run 1 + 2015 and 2016 data samples
- $\boldsymbol{B_s^0 \to D^{\mp}K^{\pm}\pi^{\pm}\pi^{\mp}}$: the time-dependent and model – independent analysis of using the full Run 1 & 2 data samples.
- $\boldsymbol{B^+ \to Dh^+, D \to K_S^0 h^+ h^-}$: the Run 1 & 2 analysis independent of the modelling of the D-decay amplitude.
- $\boldsymbol{B^+ \to D^{(*)}h^{\pm}}$: the Run 1 & 2 simultaneous measurement of B^+ decay to D^{*0} and D^0

[LHCb–CONF–2020–003]

B decay	D decay	Method	Ref.	Dataset	Status since Ref. [3]
$B^+ \to Dh^+$	$D \to h^+h^-$	GLW/ADS	[16]	Run 1+2	**Updated**
$B^+ \to Dh^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[24]	Run 1	As before
$B^+ \to Dh^+$	$D \to h^+h^-\pi^0$	GLW/ADS	[25]	Run 1	As before
$B^+ \to Dh^+$	$D \to K_S^0 h^+h^-$	BPGGSZ	[17]	Run 1+2	**Updated**
$B^+ \to Dh^+$	$D \to K_S^0 K^{\pm}\pi^{\mp}$	GLS	[20]	Run 1+2	**Updated**
$B^+ \to D^*h^+$	$D \to h^+h^-$	GLW/ADS	[16]	Run 1+2	**Updated**
$B^+ \to DK^{*+}$	$D \to h^+h^-$	GLW/ADS	[26]	Run 1+2(*)	As before
$B^+ \to DK^{*+}$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[26]	Run 1+2(*)	As before
$B^+ \to DK^+\pi^+\pi^-$	$D \to h^+h^-$	GLW/ADS	[27]	Run 1	As before
$B^0 \to DK^{*0}$	$D \to h^+h^-$	GLW/ADS	[21]	Run 1+2(*)	**Updated**
$B^0 \to DK^{*0}$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[21]	Run 1+2(*)	**New**
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz	[22]	Run 1	**Superseded**
$B^0 \to DK^{*0}$	$D \to K_S^0\pi^+\pi^-$	BPGGSZ	[28]	Run 1	As before
$B^0 \to D^{\mp}\pi^{\pm}$	$D^{\pm} \to K^{\mp}\pi^{\pm}\pi^{\pm}$	TD	[29]	Run 1	As before
$B_s^0 \to D_s^{\mp}K^{\pm}$	$D_s^{\pm} \to h^{\pm}h^{\mp}\pi^{\pm}$	TD	[30]	Run 1	As before
$B_s^0 \to D_s^{\mp}K^{\pm}\pi^{\pm}\pi^{\mp}$	$D_s^{\pm} \to h^{\pm}h^{\mp}\pi^{\pm}$	TD	[23]	Run 1+2	**New**

$B^0 \to DK^{*0}$

[JHEP 08 (2019) 041]

Updated result from 2014 over Run 1 and Run 2 data sample of 4.8 fb^{-1}

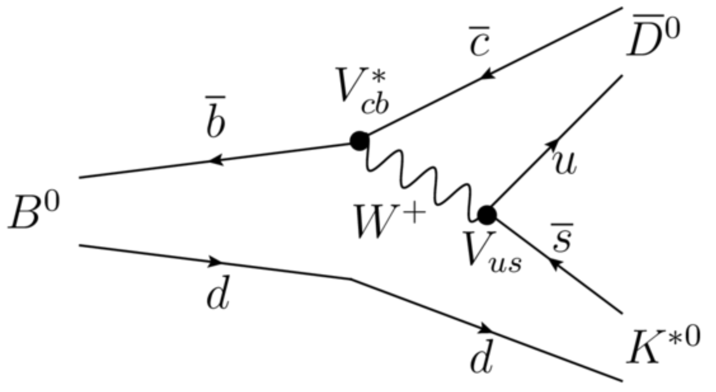
- Two-body (GLW):

$$D^0 \to K^{\pm}K^{\mp},$$
$$D^0 \to K^{\pm}\pi^{\mp},$$
$$D^0 \to \pi^{\pm}\pi^{\mp}$$

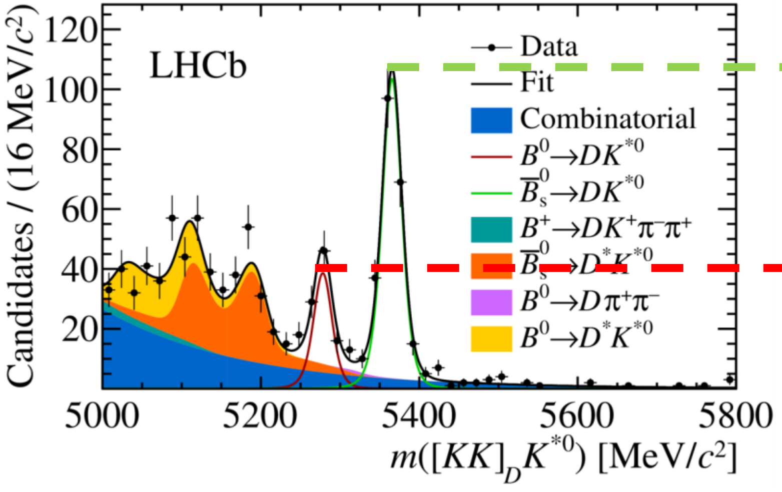
- Four-body (quasi-GLW):

NEW!

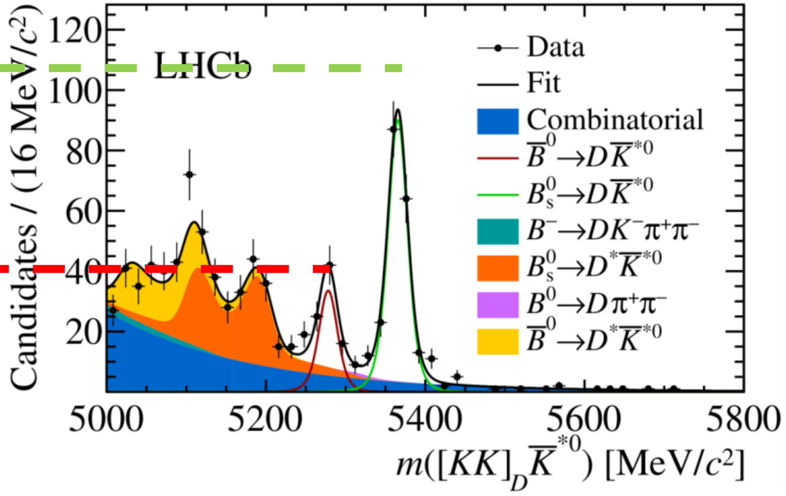
$$D^0 \to K^{\pm}\pi^{\mp}\pi^{+}\pi^{-},$$
$$D^0 \to \pi^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$$

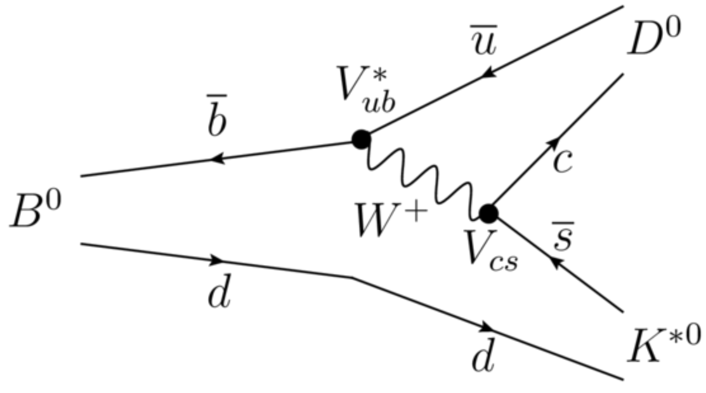


$B^0 \to DK^{*0}$ $D^0 \to K^{\pm}K^{\mp}$



$B^0 \to DK^{*0}$ $D^0 \to K^{\pm}K^{\mp}$

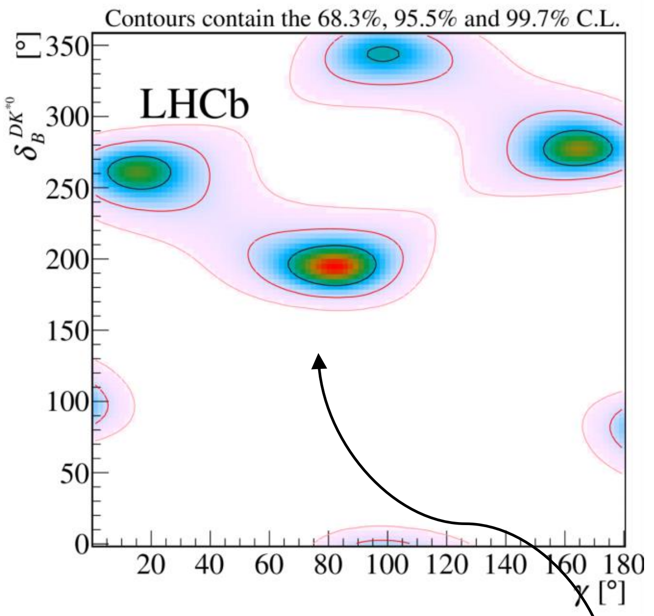


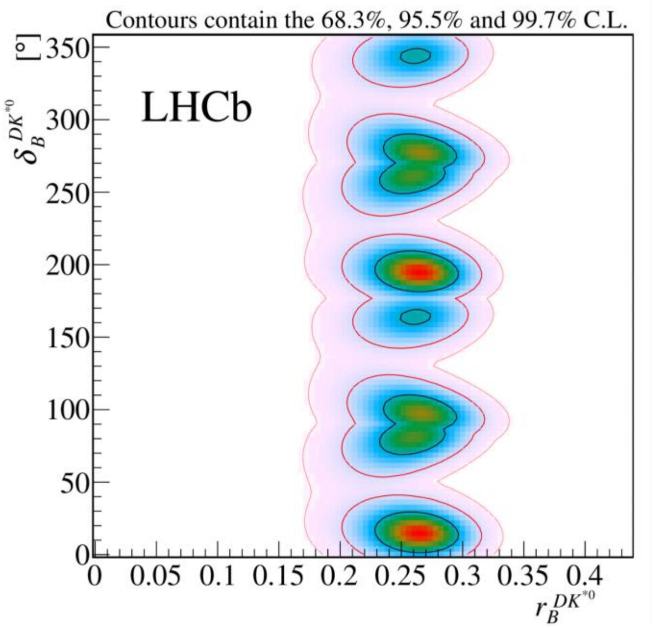


$B^0 \to DK^{*0}$

[JHEP 08 (2019) 041]

The 2D scans of $\delta_B^{DK^{*0}}$ vs. γ and $\delta_B^{DK^{*0}}$ versus $r_B^{DK^{*0}}$





$\Delta\chi^2$ = 2.30, 6.18 and 11.8 contours $\longleftrightarrow$ 68.6%, 95.5% and 99.7% C.L

Excellent constrains on the γ angle value!

Measurement of CP parameters:

$$\begin{aligned}
\mathcal{A}_{\rm ADS}^{\pi K} &= 0.19 \pm 0.19 \pm 0.01, \\
\mathcal{R}_{\rm ADS}^{\pi K} &= 0.080 \pm 0.015 \pm 0.002, \\
\mathcal{A}_{\rm ADS}^{\pi K\pi\pi} &= -0.01 \pm 0.24 \pm 0.01, \\
\mathcal{R}_{\rm ADS}^{\pi K\pi\pi} &= 0.073 \pm 0.018 \pm 0.002.
\end{aligned}$$

GLW

$$A_{CP} = \frac{2\kappa r_B^{DK^{*0}} \sin\left(\delta_B^{DK^{*0}}\right) \sin(\gamma)}{1 + r_B^2 \pm 2 r_B \cos(\delta_B) \cos(\gamma)}$$

ADS

$$A_{CP} = \frac{2\kappa r_B^{DK^{*0}} r_D^{K^{*0}} \sin\left(\delta_B^{K^{*0}} + \delta_D^{K\pi}\right) \sin(\gamma)}{(r_B^{DK^{*0}})^2 + (r_D^{K\pi})^2 + 2\kappa r_B^{DK^{*0}} r_D^{K^{*0}} \cos\left(\delta_B^{DK^{*0}} + \delta_D^{K\pi}\right) \cos(\gamma)}$$

$B_s^0 \to D_s^- h^+\pi^+\pi^-$

[JHEP 03 (2021) 137]

Measurement of the angle γ in $B_s^0 \to D_s^- h^+\pi^+\pi^-$ decay:

(Full Run 1 & 2: 9 fb^{-1} data sample)

A time-dependent amplitude analysis:

the time-dependent amplitude fit using signal PDF through full-spectrum decay rate.

$$\langle f|B_s^0\rangle = A^c(x) \quad \langle f|\overline{B_s^0}\rangle = re^{i(\delta-\gamma)}A^u(x)$$

$$A^u(x) = \sum_i a_i^u A_i(x)$$

$$A^c(x) = \sum_i a_i^c A_i(x)$$

A model-independent analysis:

(phase-space integrated decay rate)

Measurement of the CP coefficients:

$$C_f, A_f^{\Delta\Gamma}, A_{\bar f}^{\Delta\Gamma}, S_f, S_{\bar f}$$

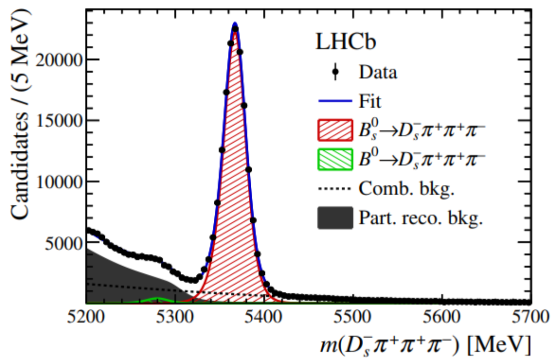
$$S_f = f\frac{2r\kappa\sin(\delta - f(\gamma-2\beta_s))}{1+r^2}$$

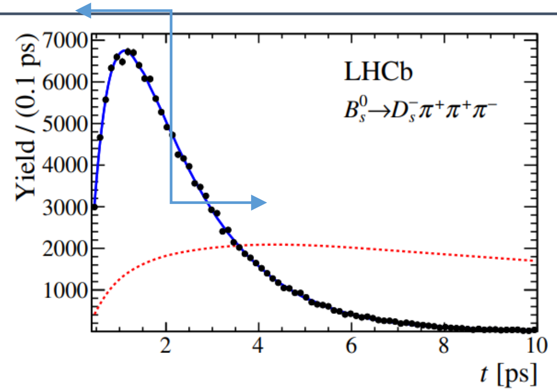
$$\frac{d\Gamma(x,t)}{e^{-\Gamma_s t}dt\,d\phi_4} \propto \left(\left|A_f^c(x)\right|^2 + r^2\left|A_f^u(x)\right|^2\right)\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + qf\overbrace{\left(\left|A_f^c(x)\right|^2 r^2\left|A_f^u(x)\right|^2\right)}^{C_f}\cos(\Delta m_s t)$$
$$\underbrace{-2Re\left(A_f^c(x)^* r\, A_f^u(x)e^{i\delta - if(\gamma-2\beta_s)}\right)}_{D_f}\sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - 2qf\underbrace{Im\left(A_f^c(x)^* r\, A_f^u(x)e^{i\delta-if(\gamma-2\beta_s)}\right)}_{S_f}\sin(\Delta m_s t)$$

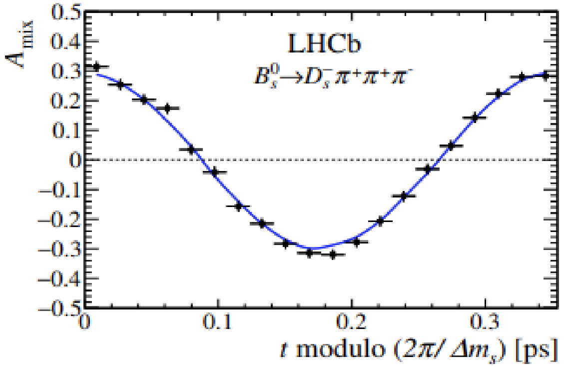
[JHEP 03 (2021) 137]

$B_s^0 \to D_s^- h^+\pi^+\pi^-$

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



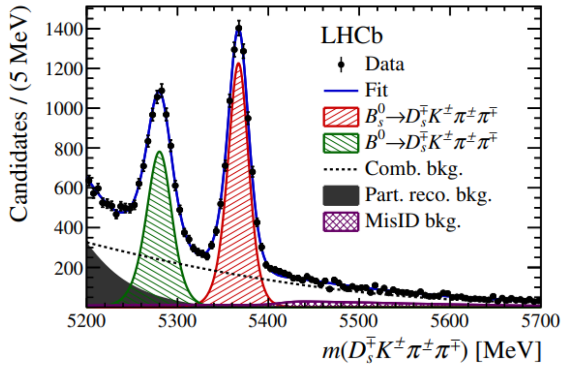


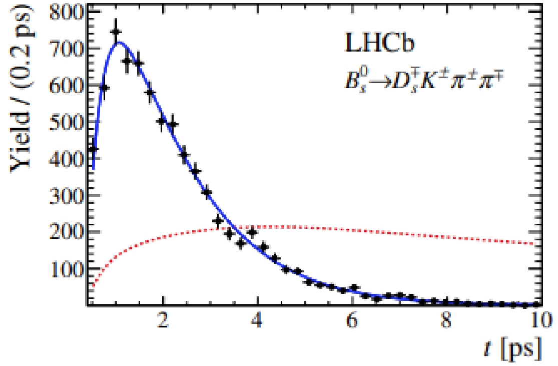


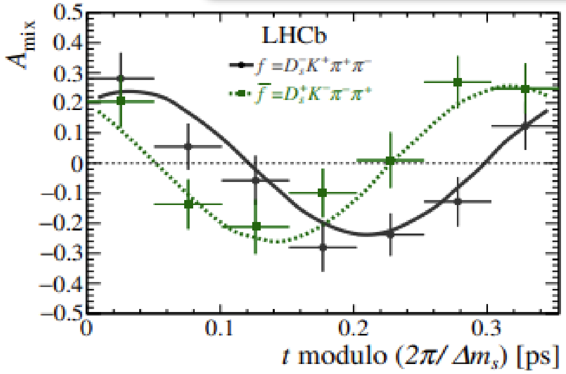
Decay-time

The mixing asymmetry folded into one oscillation period along with the fit projections

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





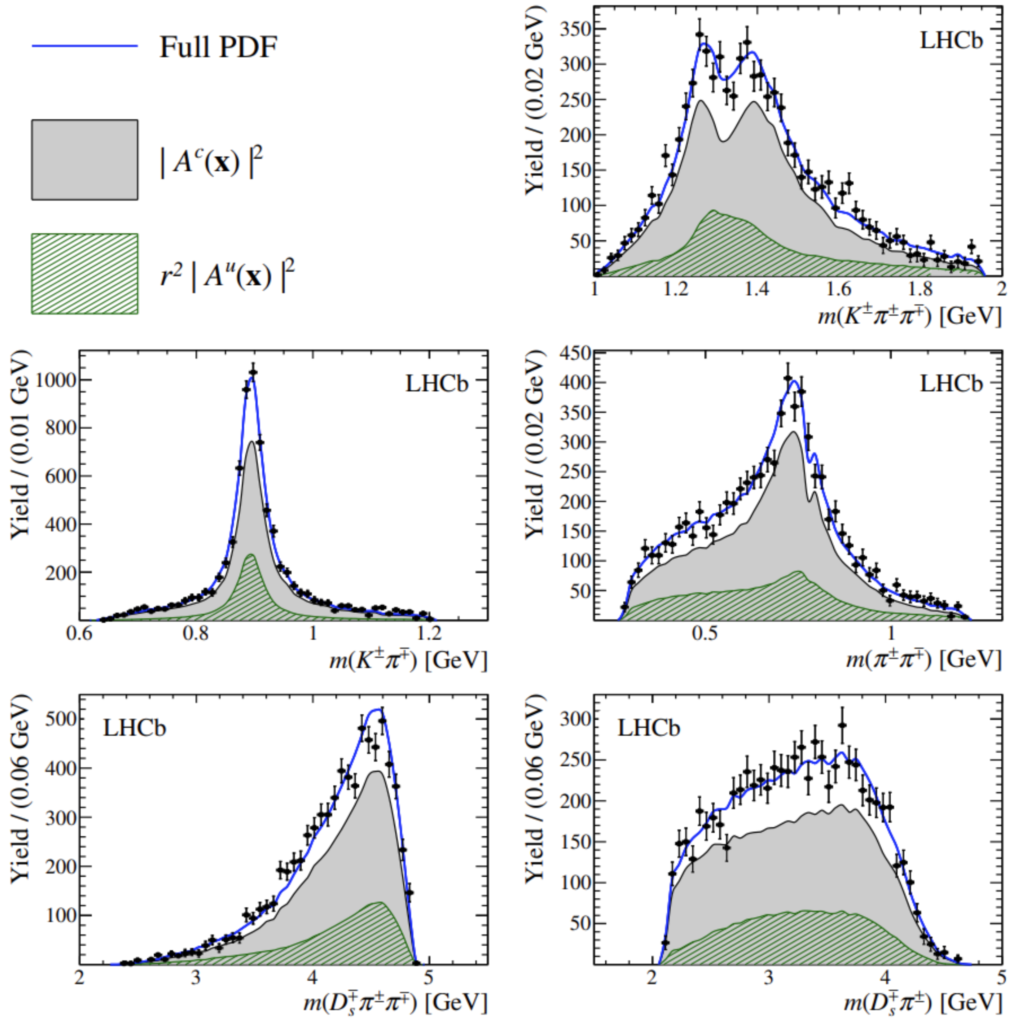


$\Delta m_s = (17.757 \pm 0.007(stat) \pm 0.008(syst))ps^{-1}$ - the most precise measurement of $\boldsymbol{\Delta m_s}$!

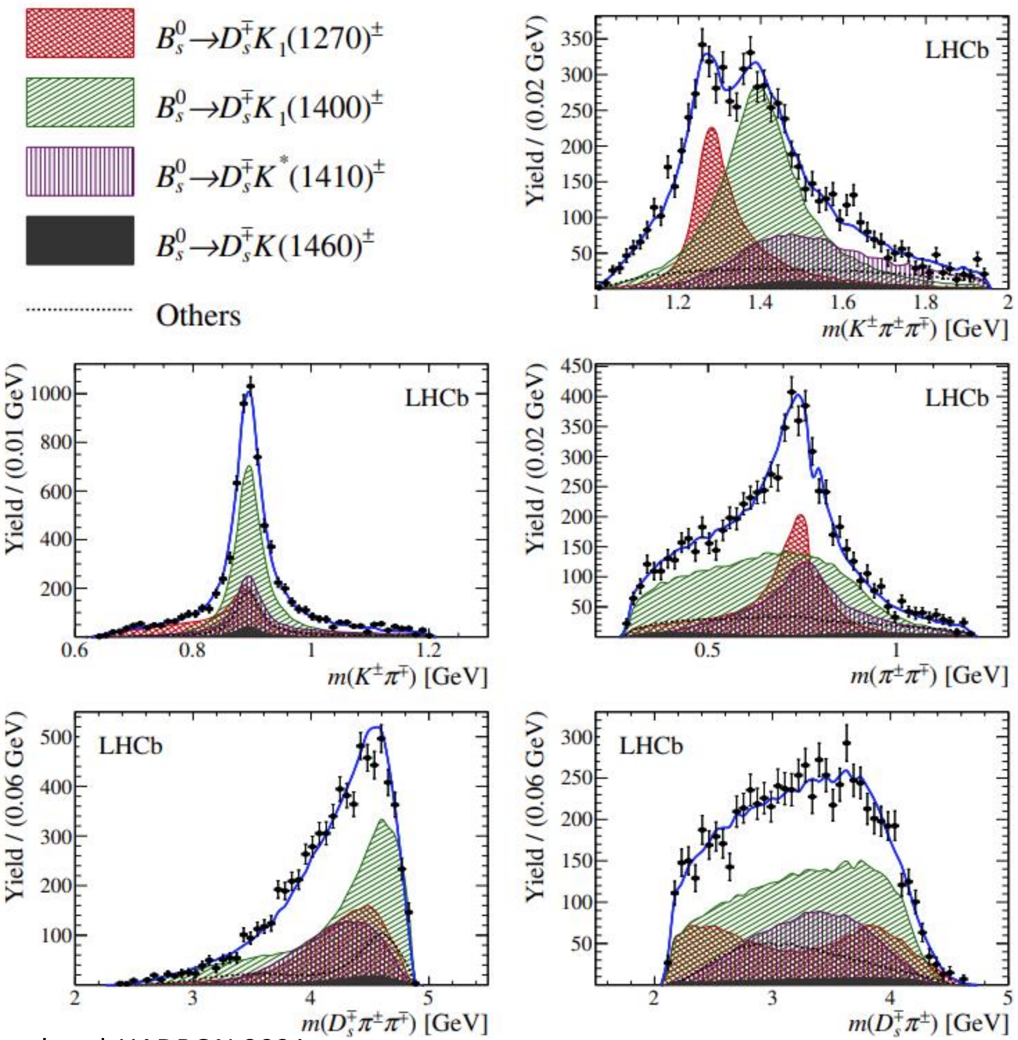
$B_s^0 \to D_s^- h^+ \pi^+ \pi^-$

[JHEP 03 (2021) 137]

Contributions from $b \to c$ and $b \to u$ decay amplitudes



Incoherent contributions from intermediate-state components.



$B_s^0 \to D_s^- h^+ \pi^+ \pi^-$

[JHEP 03 (2021) 137]

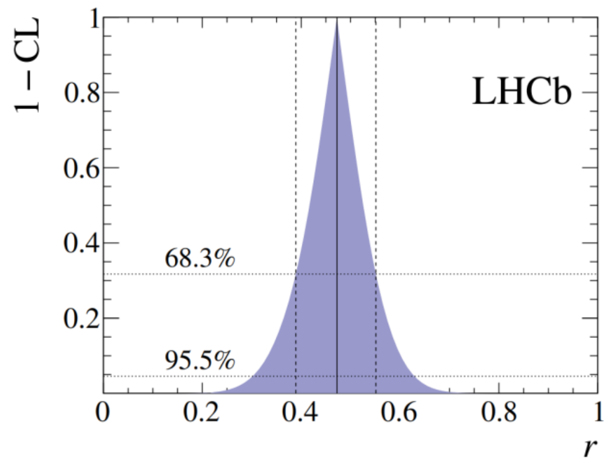
A model-independent analysis:

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	$125.7 \pm 6.4 \pm 6.9 \pm 19.9$	$88.1 \pm 7.0 \pm 10.0 \pm 20.9$

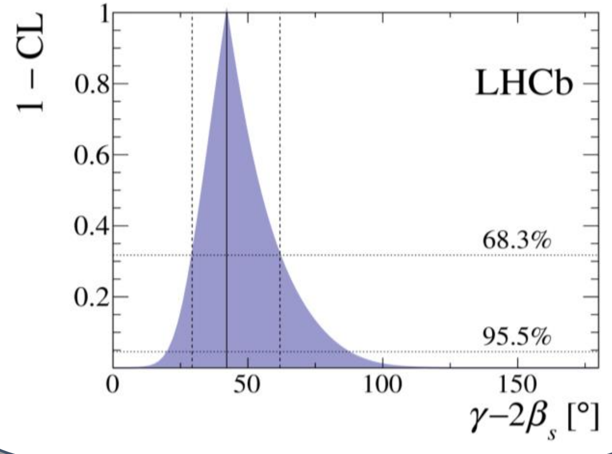
A time-dependent amplitude analysis:

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	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 [°]	$-6\,^{+10}_{-12}\,^{+2}_{-4}$	$-14 \pm 10 \pm 4 \pm 5$
$\gamma - 2\beta_s$ [°]	$42\,^{+19}_{-13}\,^{+6}_{-2}$	$42 \pm 10 \pm 4 \pm 5$



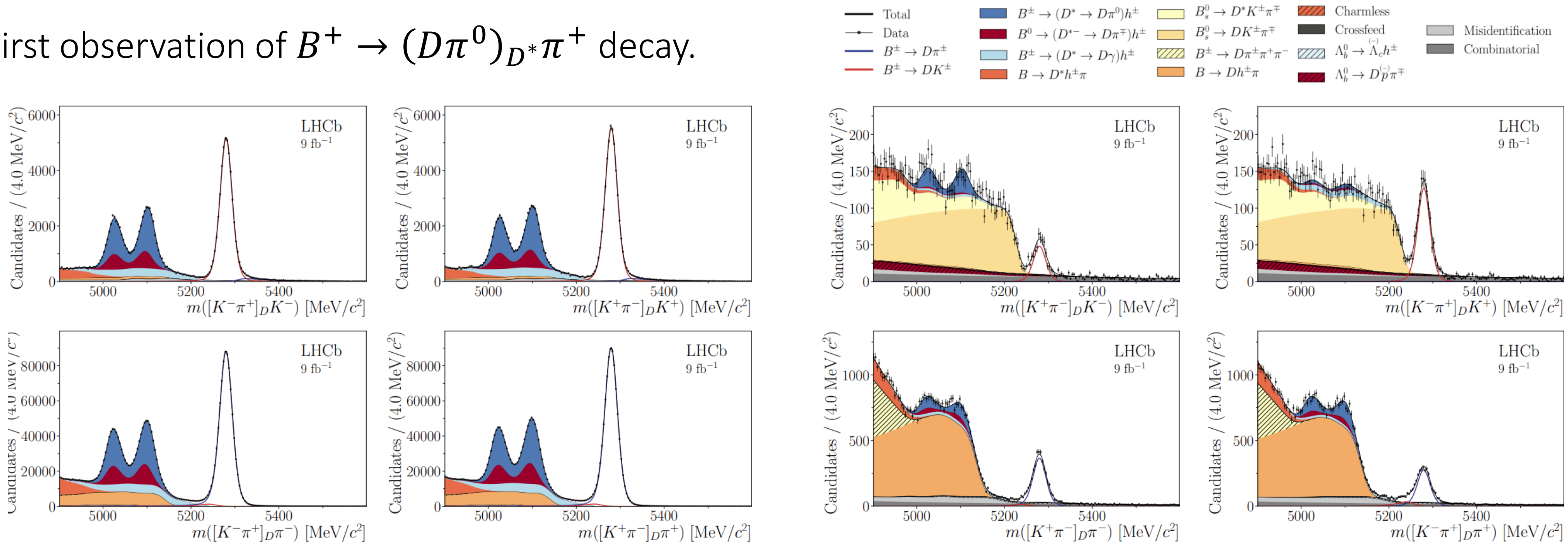
The 1−CL contours for r and γ − 2βs obtained with the model-independent fit.



$B^+ \rightarrow D^{(*)}h^+$

[JHEP 04 (2021) 081]

- The Run 1 and Run 2 data sample of 8.7 fb^{-1}
- Simultaneous D^0 and D^{*0} analysis with $D^{(*)}$ decay to $D\pi^0$ and $D\gamma$ and $D \rightarrow K^{\pm}\pi^{\mp}, D \rightarrow K^{\pm}K^{\mp}\ D \rightarrow \pi^{\pm}\pi^{\mp}$
- Measurement of partially reconstructed $B^+ \rightarrow D^{(*)}K^+$ and $B^+ \rightarrow D^{(*)}\pi^+$ with $D \rightarrow \mathrm{K}^{\pm}\pi^{\mp}$.
- First observation of $B^+ \rightarrow (D\pi^0)_{D^*}\pi^+$ decay.



$B^+ \to D^{(*)} h^+$

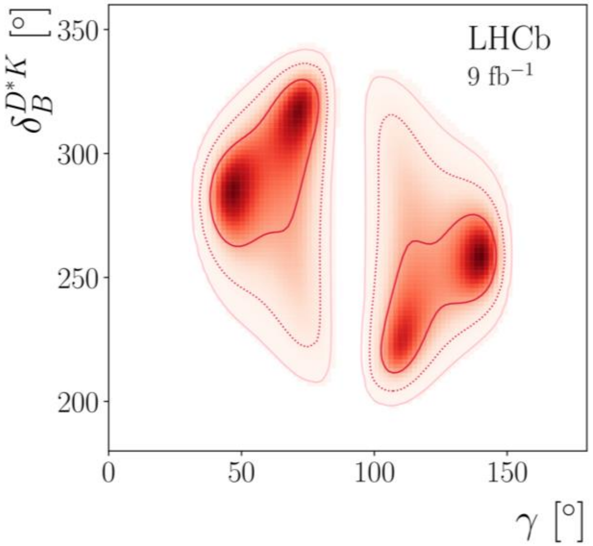
[JHEP 04 (2021) 081]

- Measurement of CP parameters provide powerful constraints on the angle γ for other LHCb measurements:

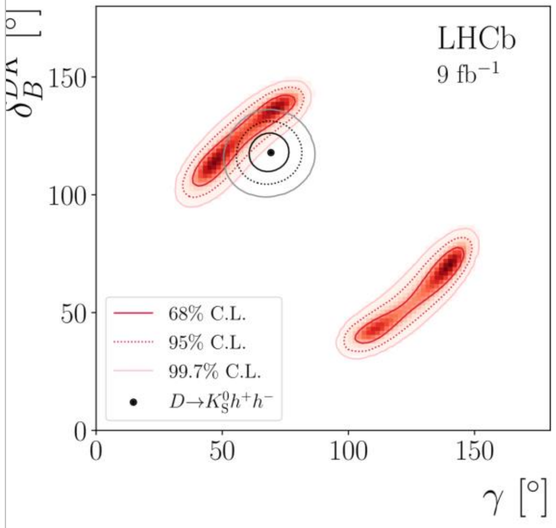
$$
\begin{aligned}
A_K^{CP} &= 0.136 \quad \pm 0.009 \quad \pm 0.001, \\
A_\pi^{CP} &= -0.008 \quad \pm 0.002 \quad \pm 0.002, \\
A_K^{K\pi} &= -0.011 \quad \pm 0.003 \quad \pm 0.002, \\
R^{CP} &= 0.950 \quad \pm 0.009 \quad \pm 0.010,
\end{aligned}
$$

……….

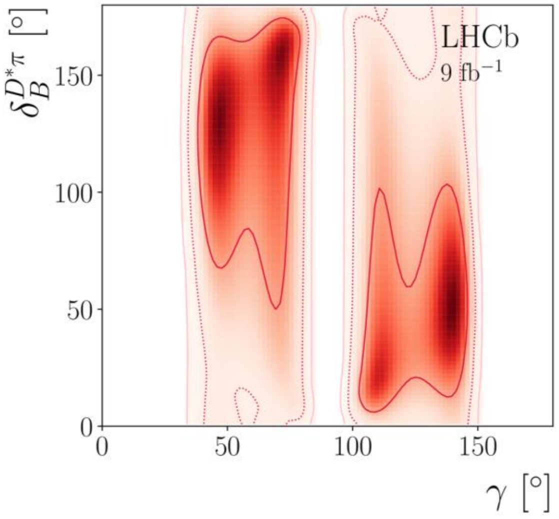
$B^+ \to DK^+$



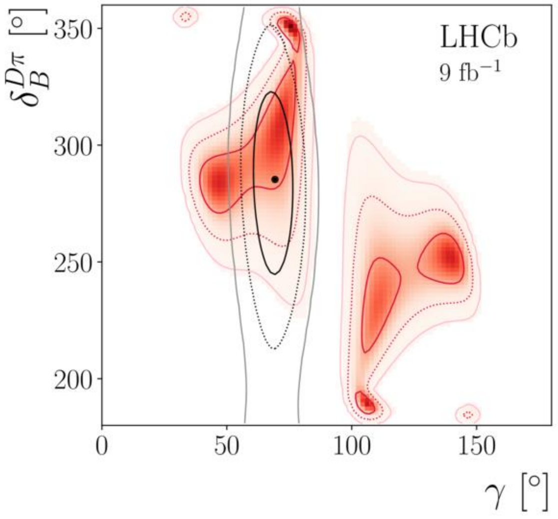
$B^+ \to D^*K^+$



$B^+ \to D\pi^+$



$B^+ \to D^*\pi^+$



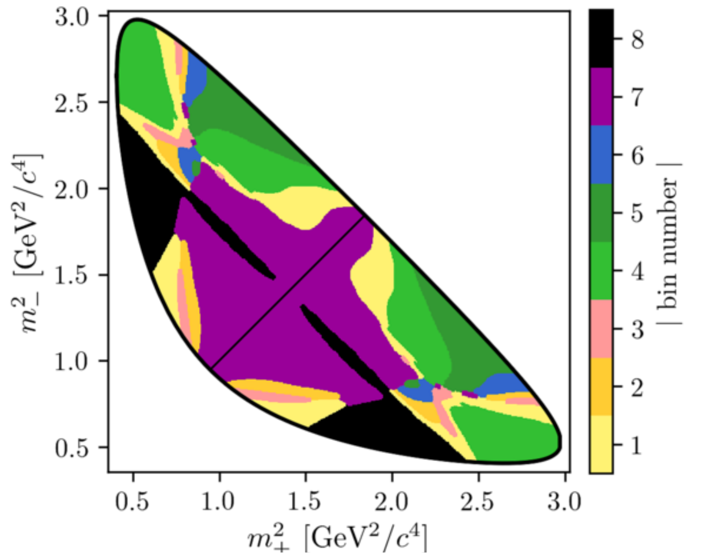
$B^+ \to Dh^+, D \to K_S^0 h^+ h^-$

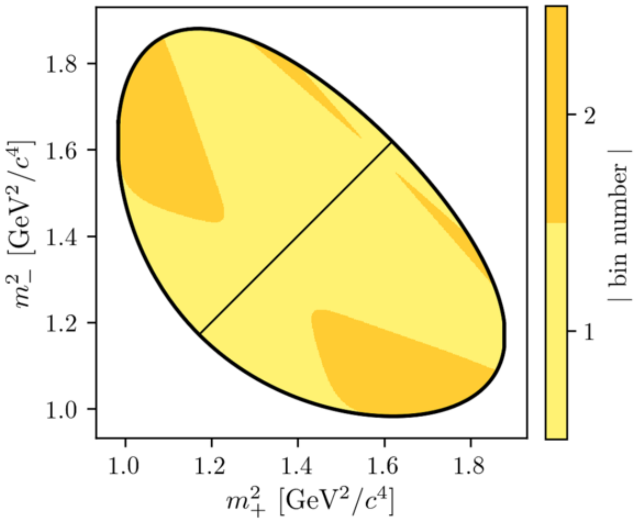
[JHEP 02 (2021) 169]

- The Run 1 and Run 2 data sample of 9 fb^{-1}
- Type of 3 body D decay analysis at LHCb:
  - **Model independent – method takes inputs from CLEO / BESIII experiments** (smaller uncertainties and smaller sensitivity to the angle γ)
  - Model dependent – method performs an amplitude analysis of D decay (bigger uncertainties and better sensitivity of the angle γ)
- Simulataneous measurements of: $\gamma, r_B^{DK},\ \delta_B^{DK}, r_B^{D\pi},\ \delta_B^{D\pi}$
- Dalitz plot analysis: measurement of the yield in each bin of the Dalitz plot.

[PR D82 112006] [PR D102 052008]

- Strong phase input: c_i , s_i measured by CLEO and BESIII

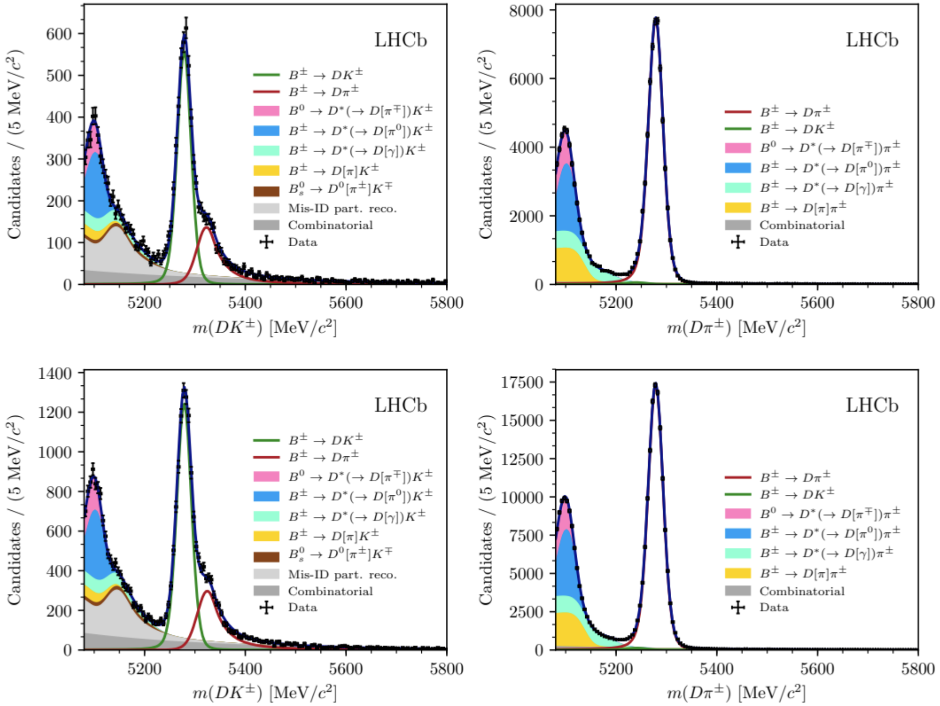




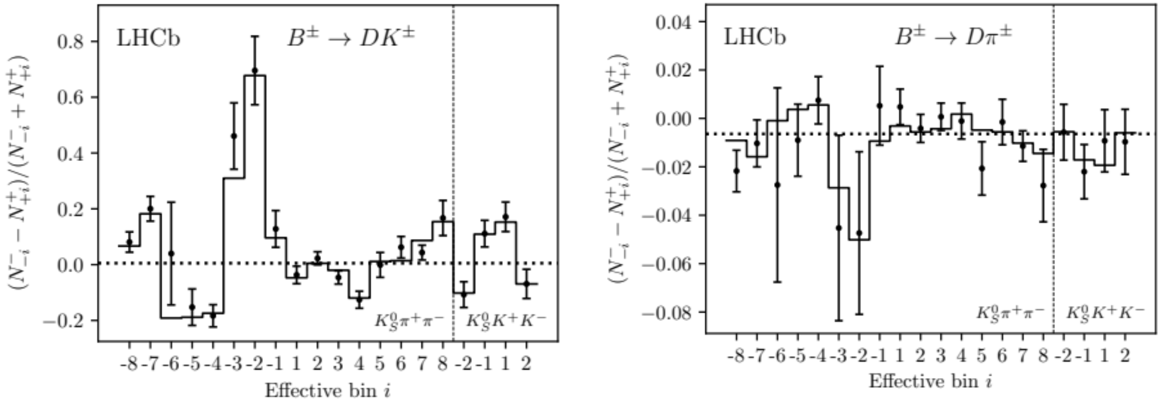
Optimal binning schemes for $D \to K_S^0 K^+ K^-$ decays and $D \to K_S^0 \pi^+ \pi^-$ decays.

$B^+ \to Dh^+, D \to K_S^0 h^+ h^-$

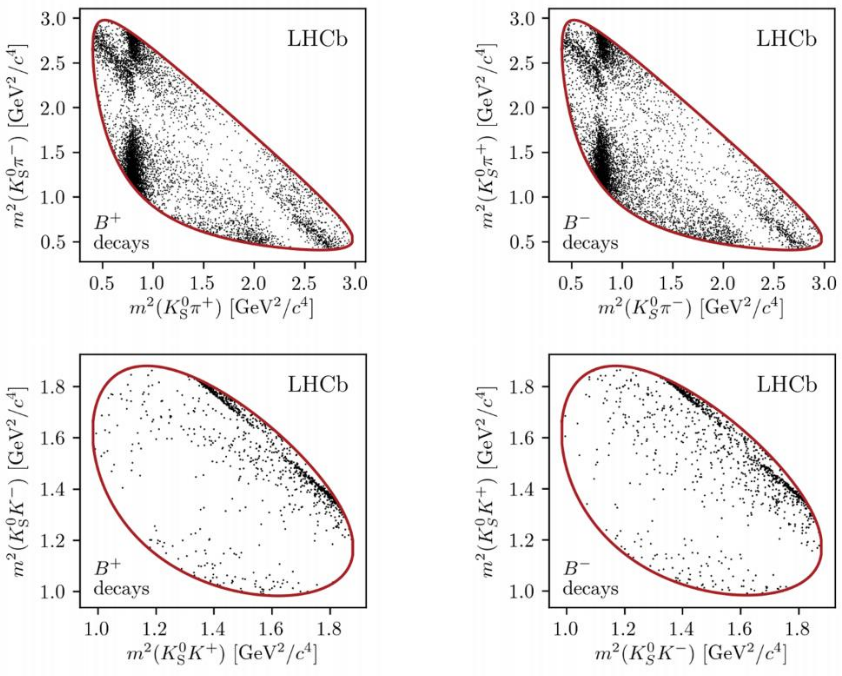
[JHEP 02 (2021) 169]



Selection of candidates and mass fit for each decay mode



Measurement of the bin-by-bin asymmetries

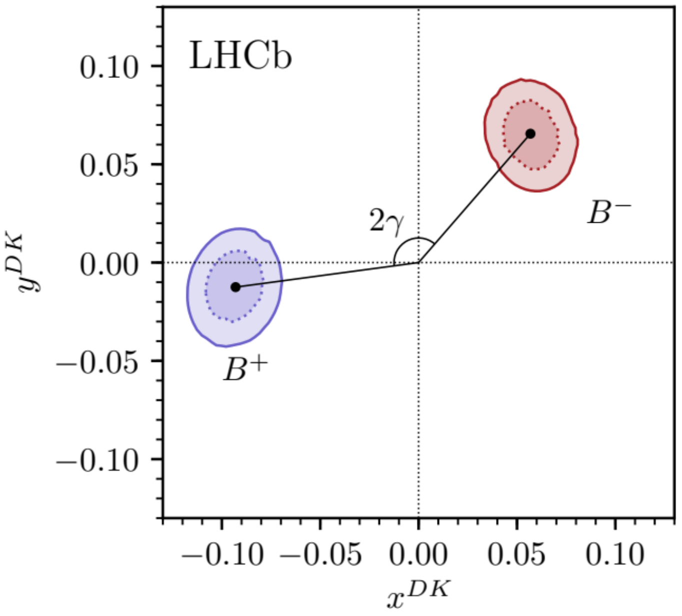


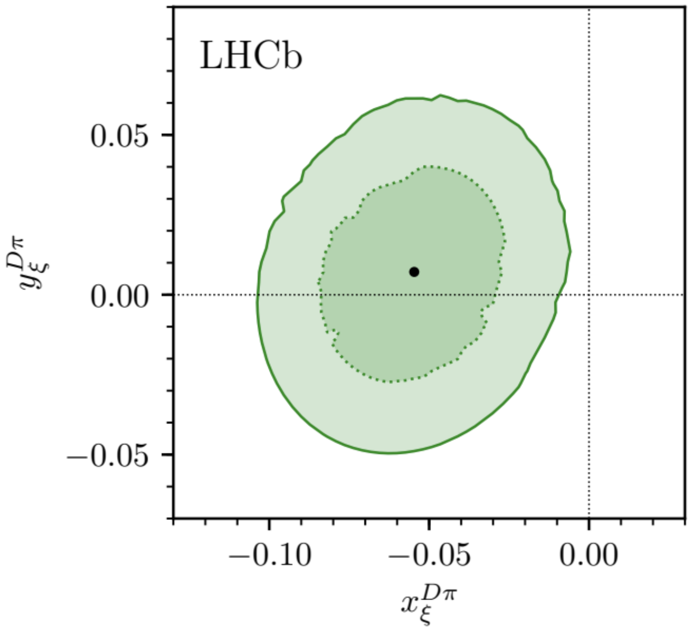
Dalitz plot analysis

$B^+ \to Dh^+, D \to K_S^0 h^+ h^-$

[JHEP 02 (2021) 169]

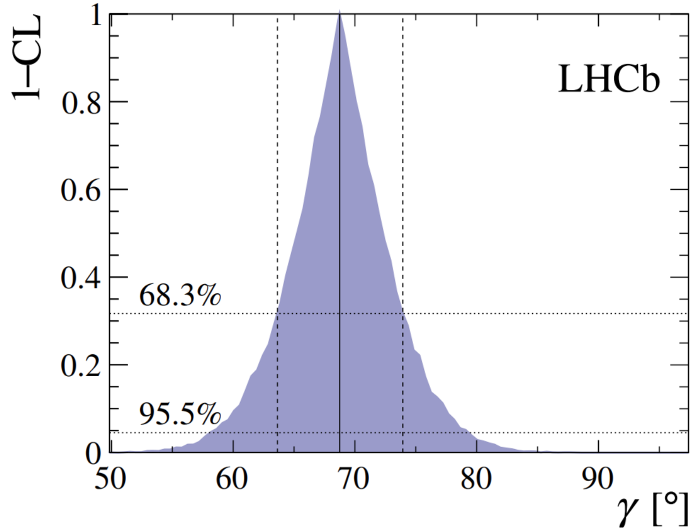
- Fit results for CPV observables:





- **The most precise single measurement of angle γ**

The 1−CL contours for angle γ

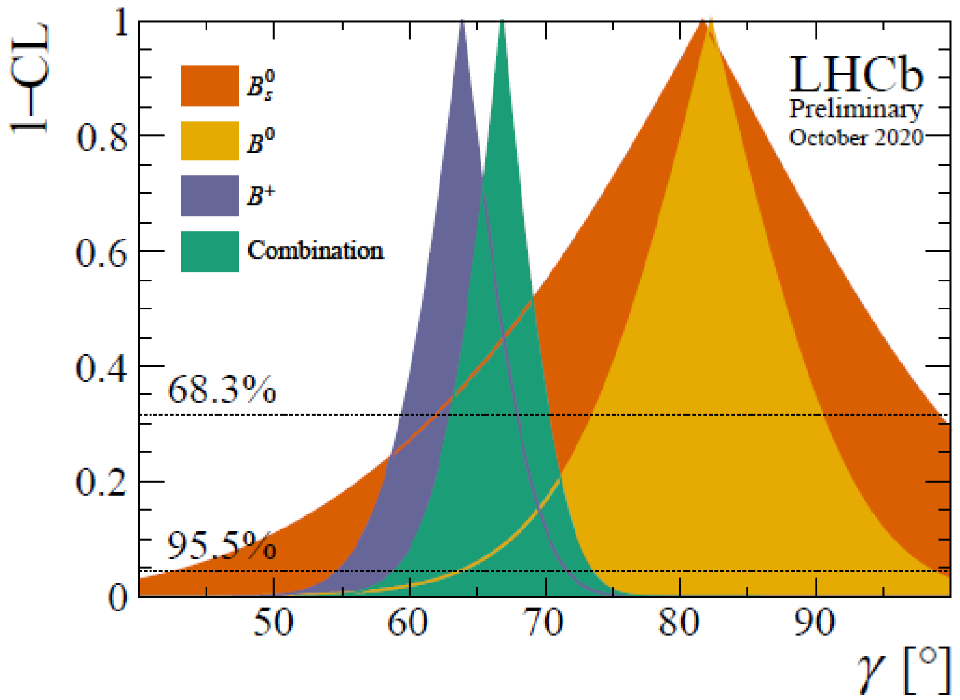


$$\gamma = (68.7^{+5.2}_{-5.1})^\circ,$$
$$r_B^{DK^\pm} = 0.0904^{+0.0077}_{-0.0075},$$
$$\delta_B^{DK^\pm} = (118.3^{+5.5}_{-5.6})^\circ,$$
$$r_B^{D\pi^\pm} = 0.0050 \pm 0.0017,$$
$$\delta_B^{D\pi^\pm} = (291^{+24}_{-26})^\circ.$$

γ combination by LHCb collaboration

[LHCb–CONF–2020–003]

- LHCb provides several CKM angle γ measurements using different:
  - B meson type (B^+, B^0, B_s^0)
  - Decay mode $(B^0 \to DK^{*0})$
  - Measurement method (GLW, ADS, …)
- LHCb combination is in excellent agreement with the indirect determinations of $\gamma = 65^{+0.9}_{-2.7}$° (CKM group) and $\gamma = 65.8 \pm 2.2$ ° (UT collaboration)



LHCb measurements :

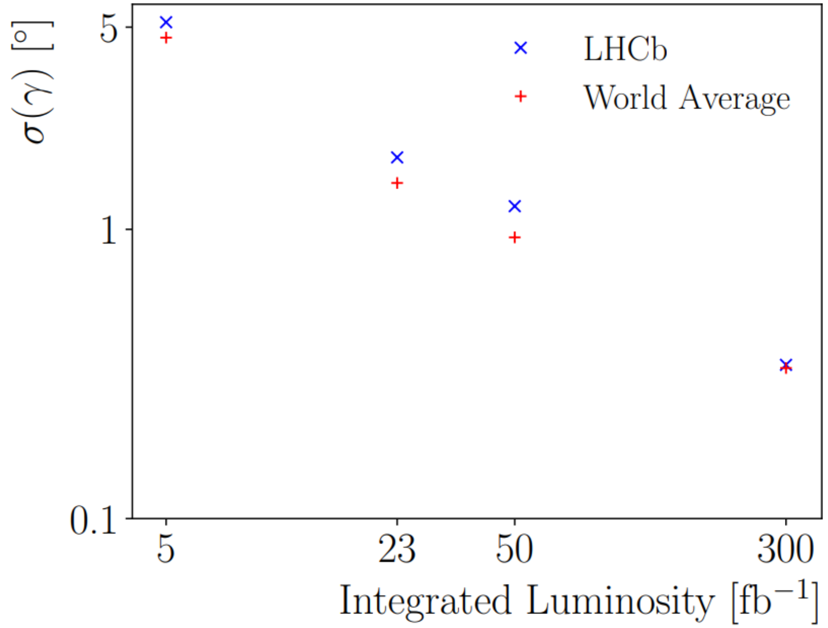
$$\gamma = 67 \pm 4\,° \; at\; 68.3\%\; C.L.$$

$$\gamma = 67^{+7}_{-8}° \; at\; 95.5\%\; C.L.$$

Summary

[CERN-LHCC-2018-027]

- Many **new** and updated results of analysis over Run 1 & 2 data.
- Exploration of decays through resonance states and multi-body final states using a different methods and variety of beauty meson decays.
- Excellent results of studies of beauty to open charm processes which is good prospects for the **Run 3 & 4** measurements.

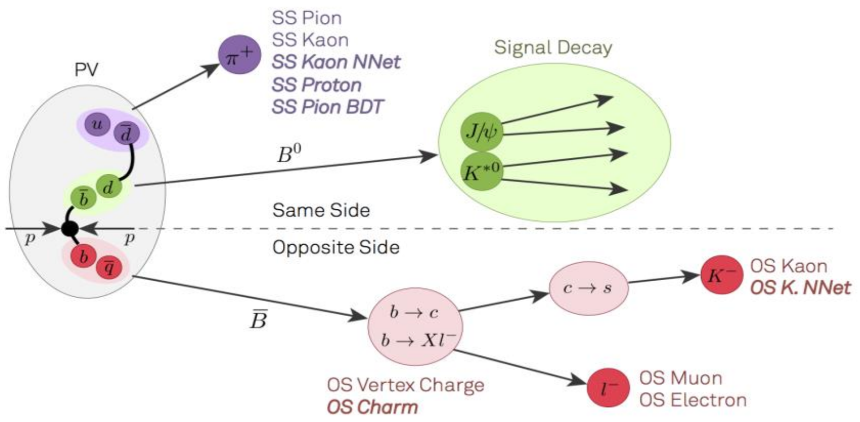


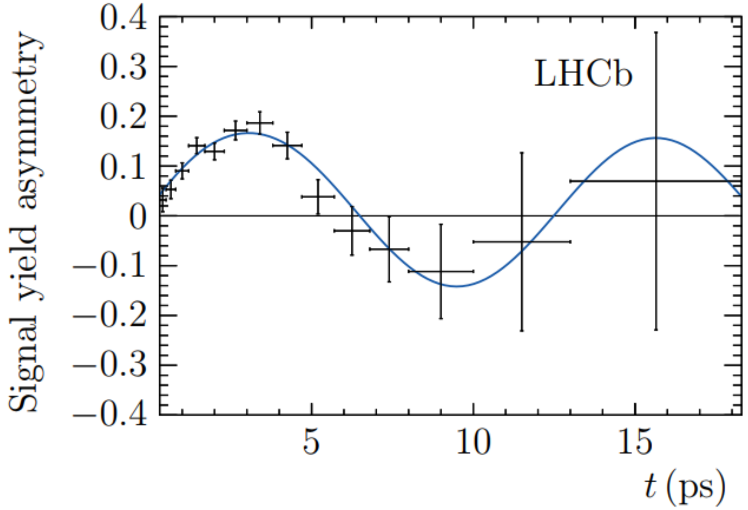
Thank you for attention.

Backup

Backup: Flavour Tagging

- Flavor tagging algorithms tag the candidate as B or $\bar{B}$ (tag decision) with some efficiency and mistag probability

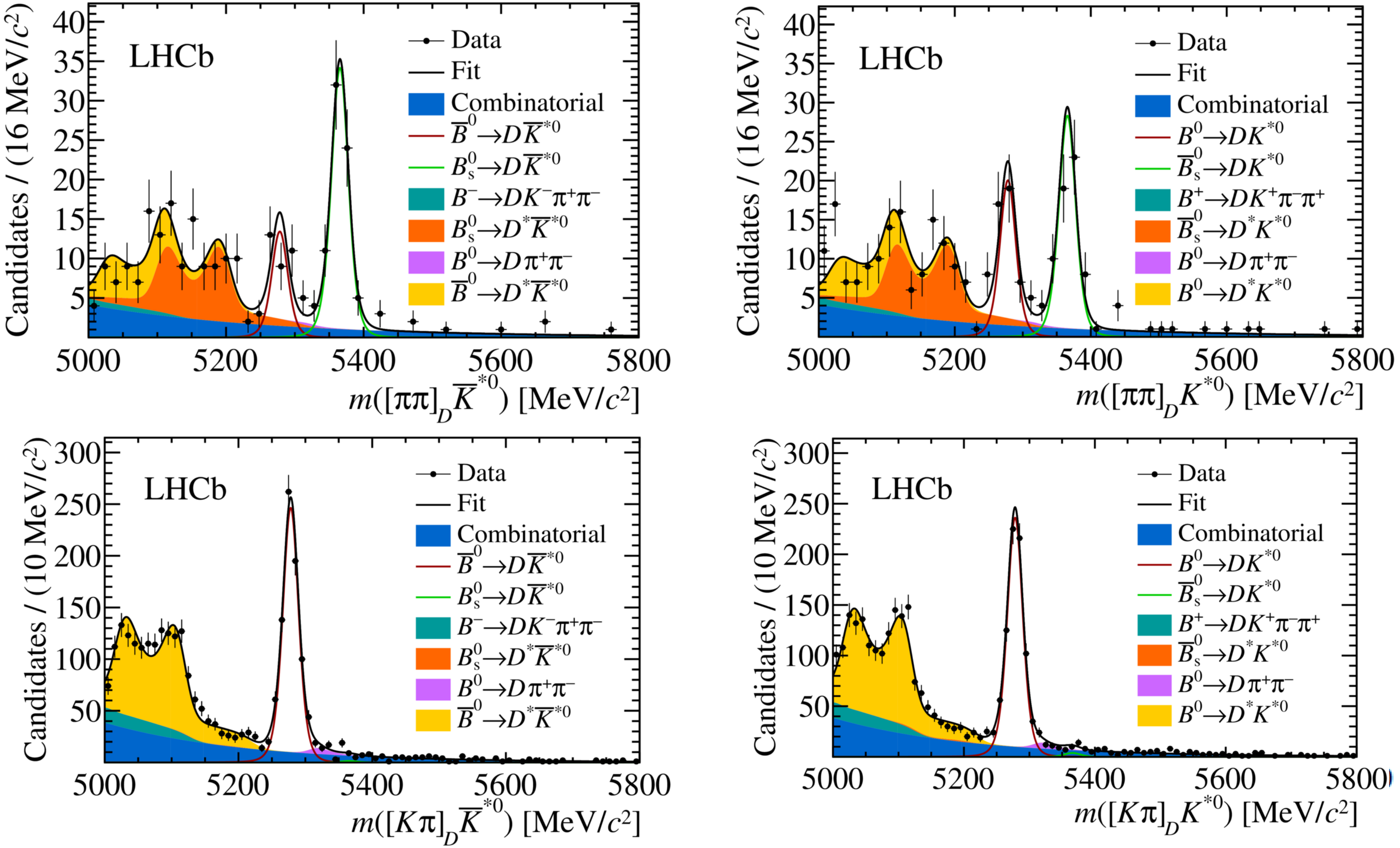




- Same Side (**SS**): correlation between flavor of the B meson and charge of the particle (pion, kaon, proton) produced close to the b-hadron in the PV.
- Opposite Side (**OS**): Correlation between flavor of the B **meson** and charged of charm meson and lepton or charge of tracks from Secondary Vertex.
- Calibrate tagging algorithm response using modes with known flavor (self-tagged,$B^+ \to J/\Psi K^+$, $B^+ \to D^0\pi^+$).

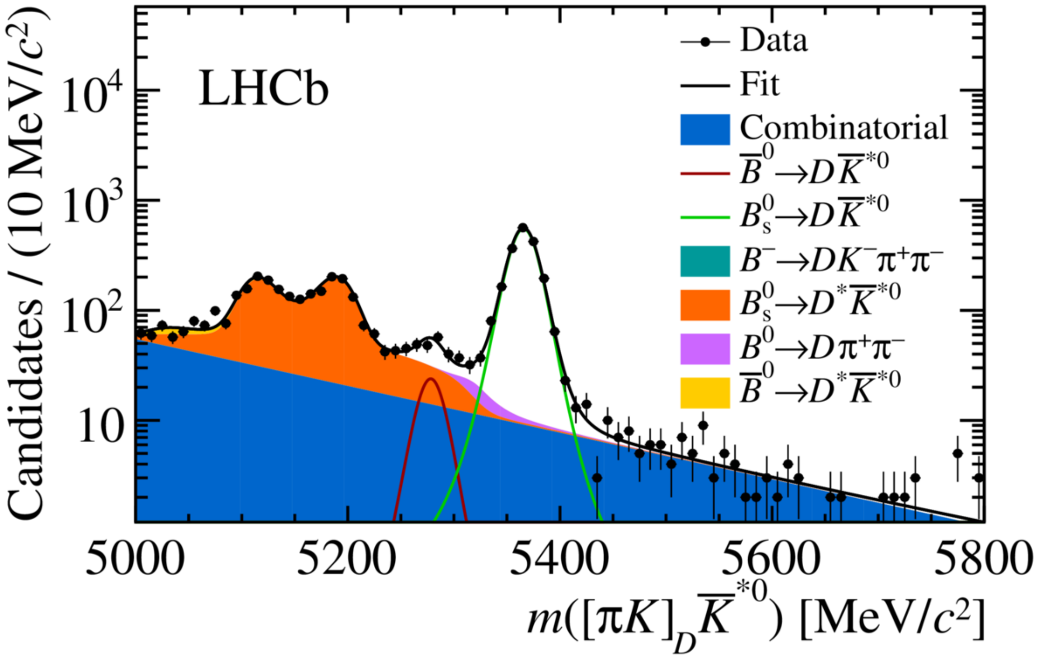
Backup: $B^0 \to DK^{*0}$

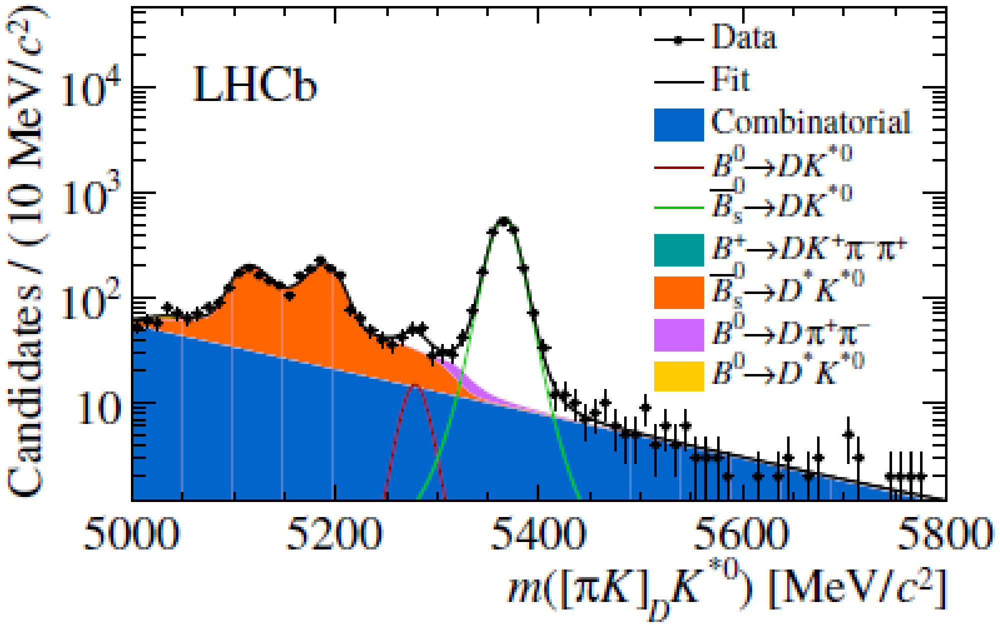
[JHEP 08 (2019) 041]



Backup: $B^0 \to DK^{*0}$

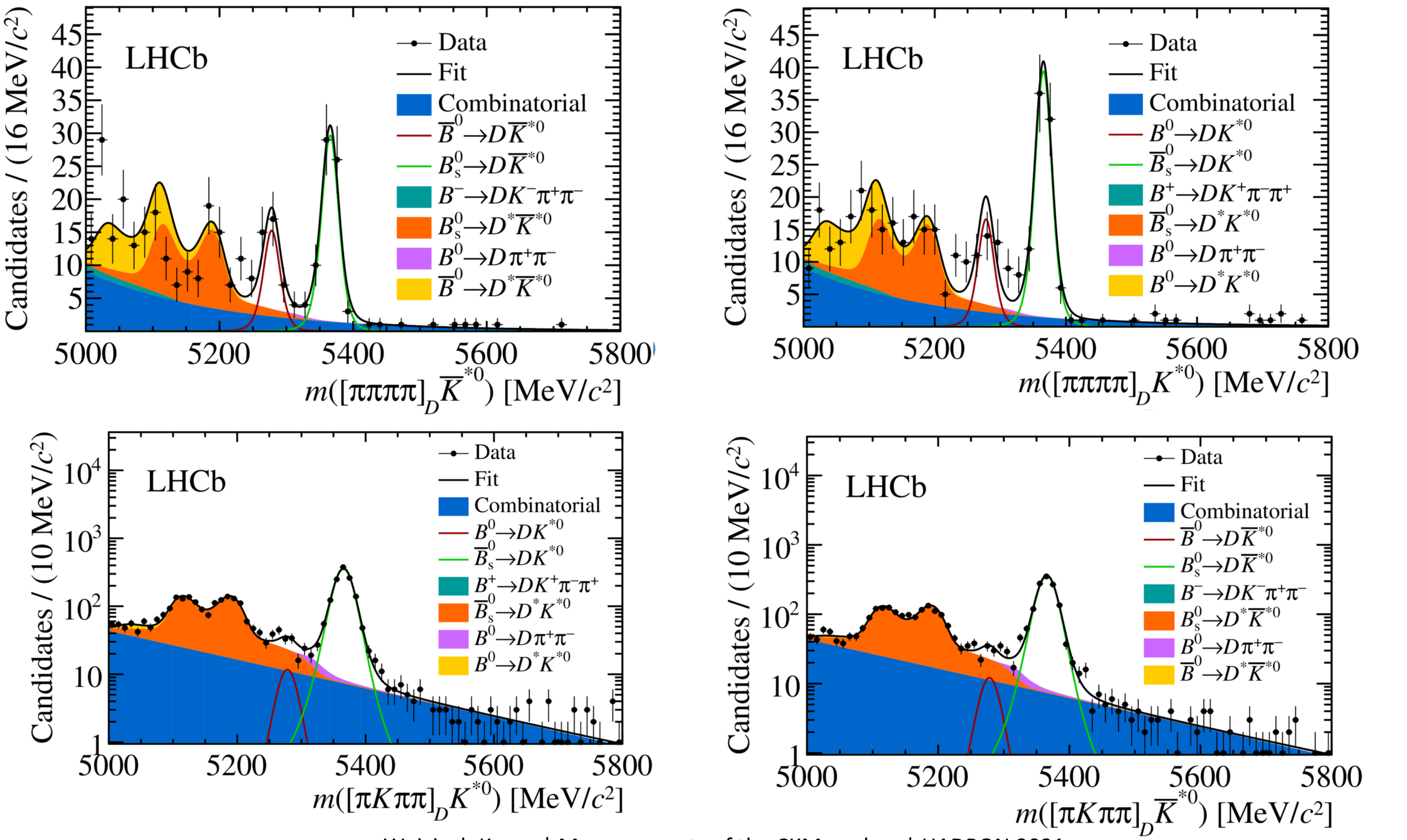
[JHEP 08 (2019) 041]





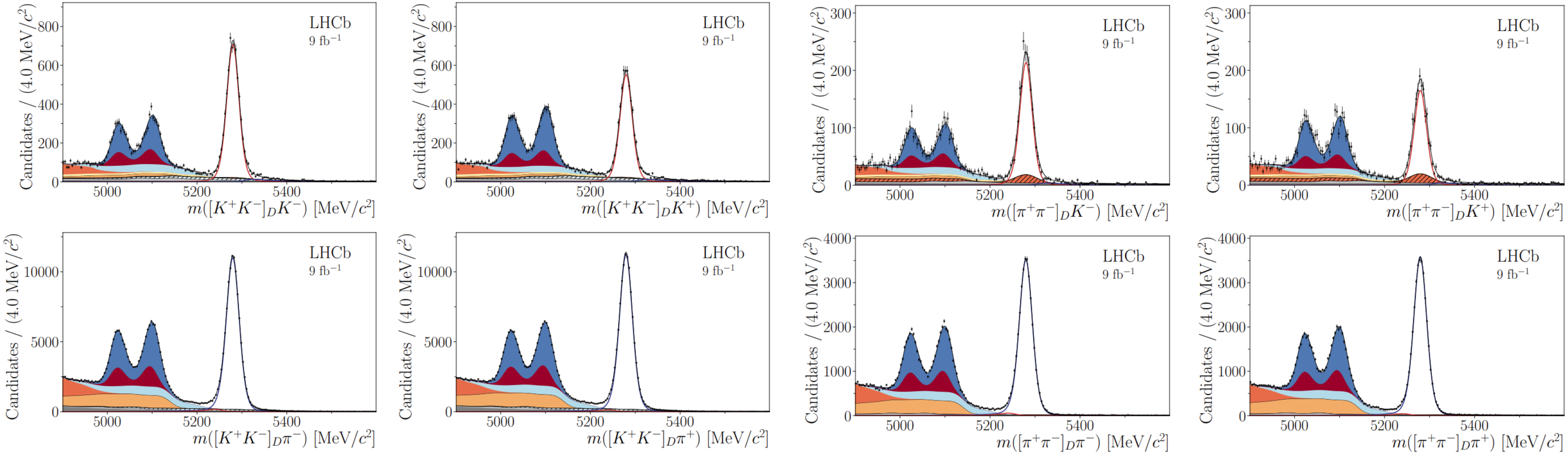
Backup: $B^0 \to DK^{*0}$

[JHEP 08 (2019) 041]



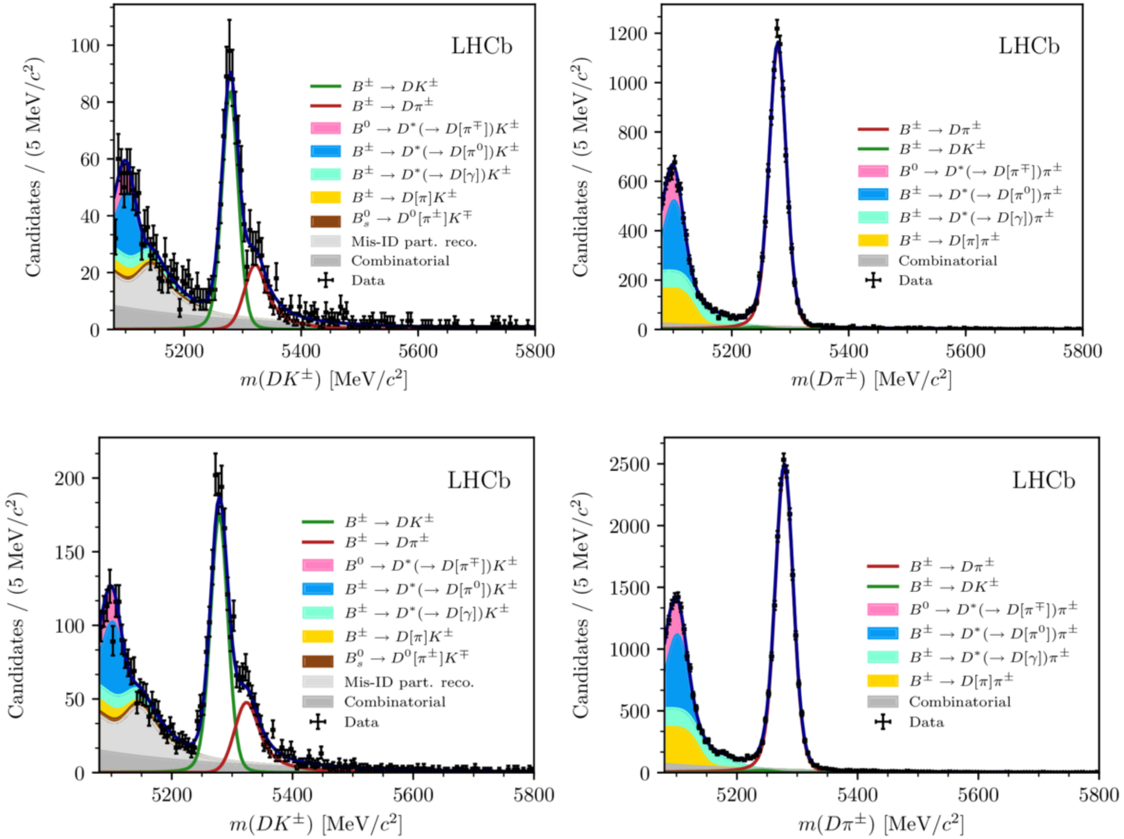
$B^+ \to D^{(*)} h^+$

[JHEP 04 (2021) 081]



$B^+ \to Dh^+, D \to K_s^0 h^+ h^-$

[JHEP 02 (2021) 169]



$$c_i \equiv \frac{\int_i dm_-^2\, dm_+^2\, |A_D(m_-^2, m_+^2)||A_D(m_+^2, m_-^2)| \cos\left[\delta_D(m_-^2, m_+^2) - \delta_D(m_+^2, m_-^2)\right]}{\sqrt{\int_i dm_-^2\, dm_+^2\, |A_D(m_-^2, m_+^2)|^2 \int_i dm_-^2\, dm_+^2\, |A_D(m_+^2, m_-^2)|^2}},$$