Recent Measurements of the CKM Angle γ at LHCb

Halime Sazak

on behalf of LHCb Collaboration

43^{rd} **International Symposium Particle in Physics Conference**

Demokritos, Athens, Greece 22 - 25 October 2024

Bundesministerium für Bildung und Forschung

FSP LHCb Erforschung von Universum und Materie

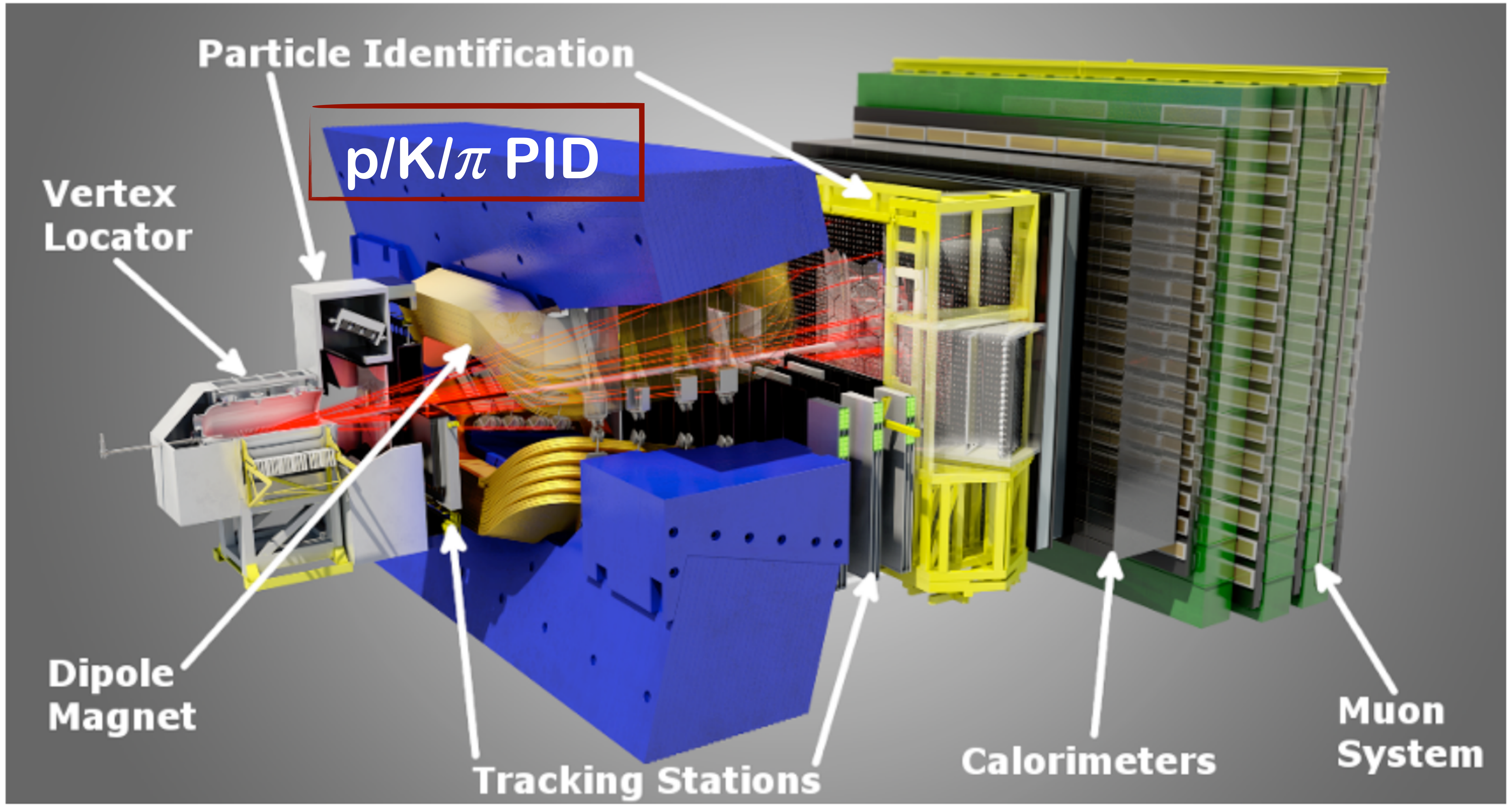
RWTH AACHEN UNIVERSITY

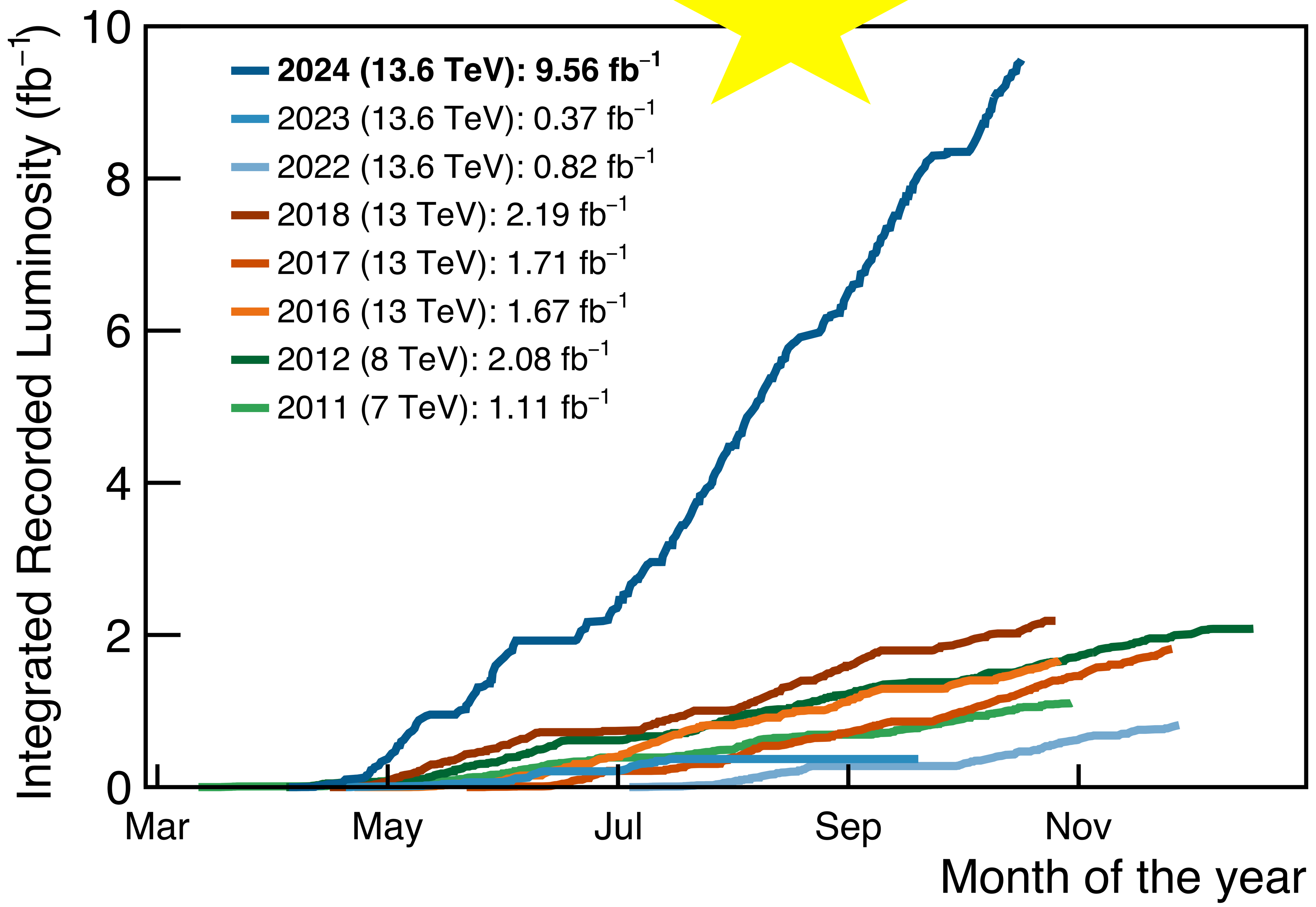
Contents

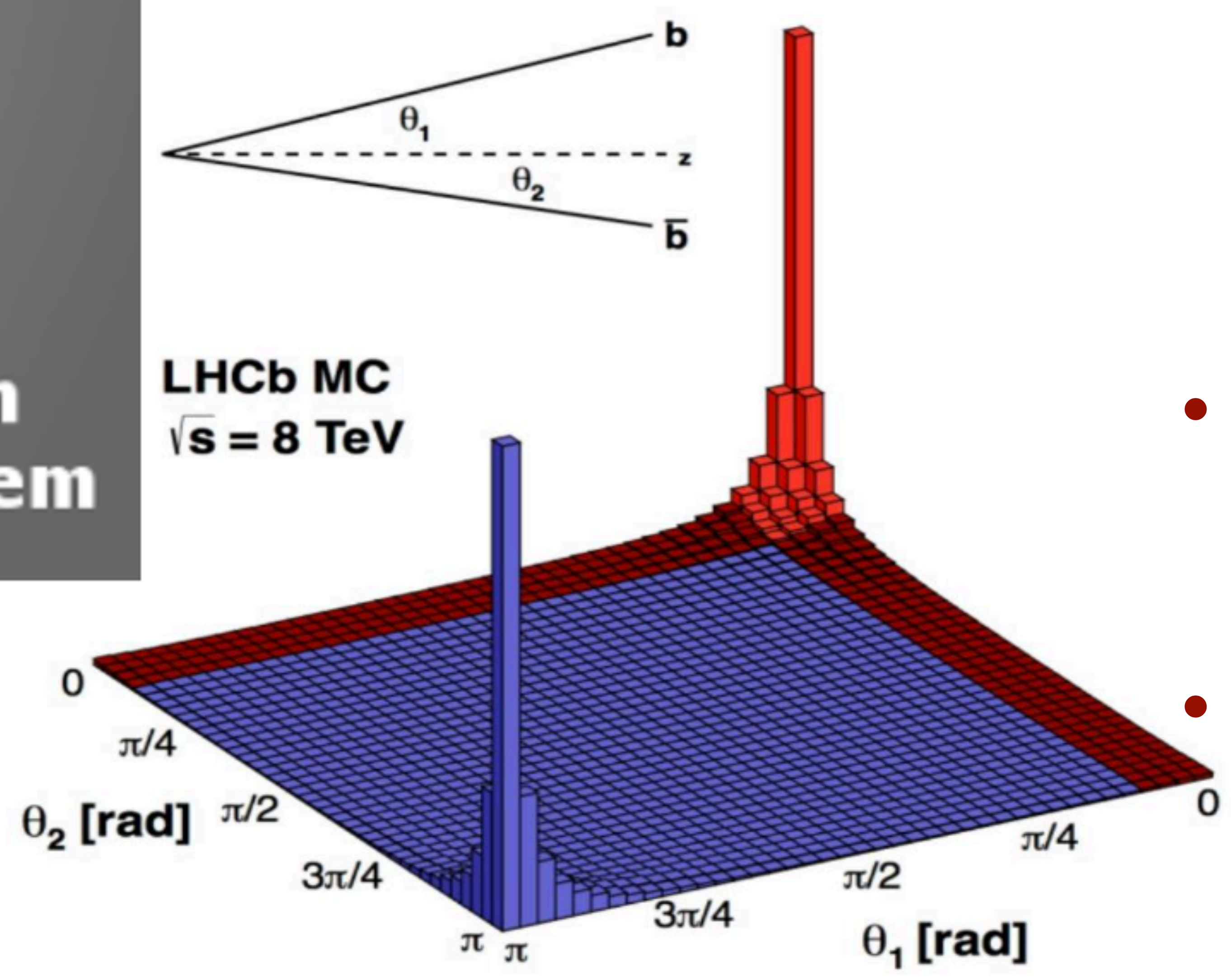
- The LHCb experiment
- Physics motivation : Why CKM angle γ measurement?
- Analyses
  - Simultaneous determination of the CKM angle γ and parameters related to the mixing
  - Measurements of the CKM angle γ using $B^{\pm} \to D^{*}h^{\pm}$ channels
  - A model independent measurement of the CKM angle γ in partially reconstructed $B^{\pm} \to D^{*}h^{\pm}$ decays with $D \to K^0_S h^+ h^- (h = \pi, K)$
  - Measurement of the CKM angle γ in the $B^0 \to DK^{*0}$ channel using self-conjugate $D \to K^0_S h^+ h^-$ decays
  - Study of CP violation in $B^0 \to DK^{*}(892)^0$ decays with $D \to K\pi(\pi\pi), \pi\pi(\pi\pi), KK$ final states
  - Measurement of the CKM angle γ in $B^{\pm} \to DK^{*}(892)^{\pm}$ decays
  - Measurement of CP asymmetry in $B^0_s \to D^{\mp}_s K^{\pm}$ decays
- Conclusion

LHCb: Large Hadron Collider Beauty Experiment

- **Precision measurements of particles containing b & c quarks mainly produced in the forward direction at LHC**
- **A single-arm forward spectrometer covering the pseudo-rapidity range $2 < \eta < 5$**
- **Precise vertexing, tracking, particle identification and the reconstruction**







- **Run1**
  - $1\, fb^{-1}$@ 7 TeV - (2012)
  - $2\, fb^{-1}$@ 8 TeV - (2011)
- **Run2**
  - $6\, fb^{-1}$@ 13 TeV - (2015 - 2018)
- **Run3**
  - Increasing luminosity @ 13.6 TeV

Physics motivation : CKM matrix and unitary conditions

- The rates of the decay processes are parametrized by the CKM matrix elements

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

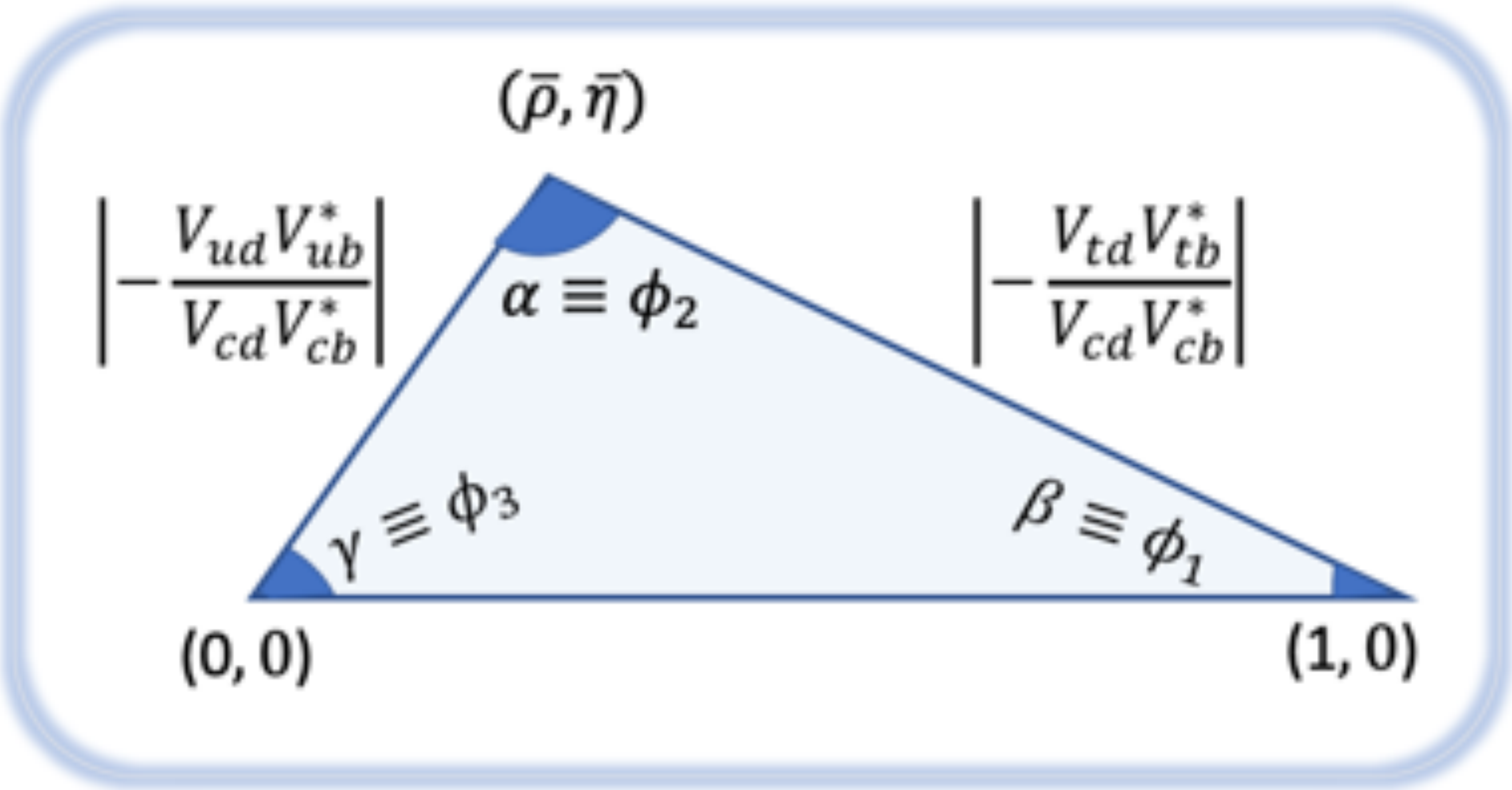
- Overconstraining the CKM elements precisely is one of the key goal of the **Flavour Physics**

- 4 parameters: A, λ, ρ, η
  - 3 angles
  - 1 complex phase

- Parameters are obtained and tested wrt data (rich pheno and large mass range):

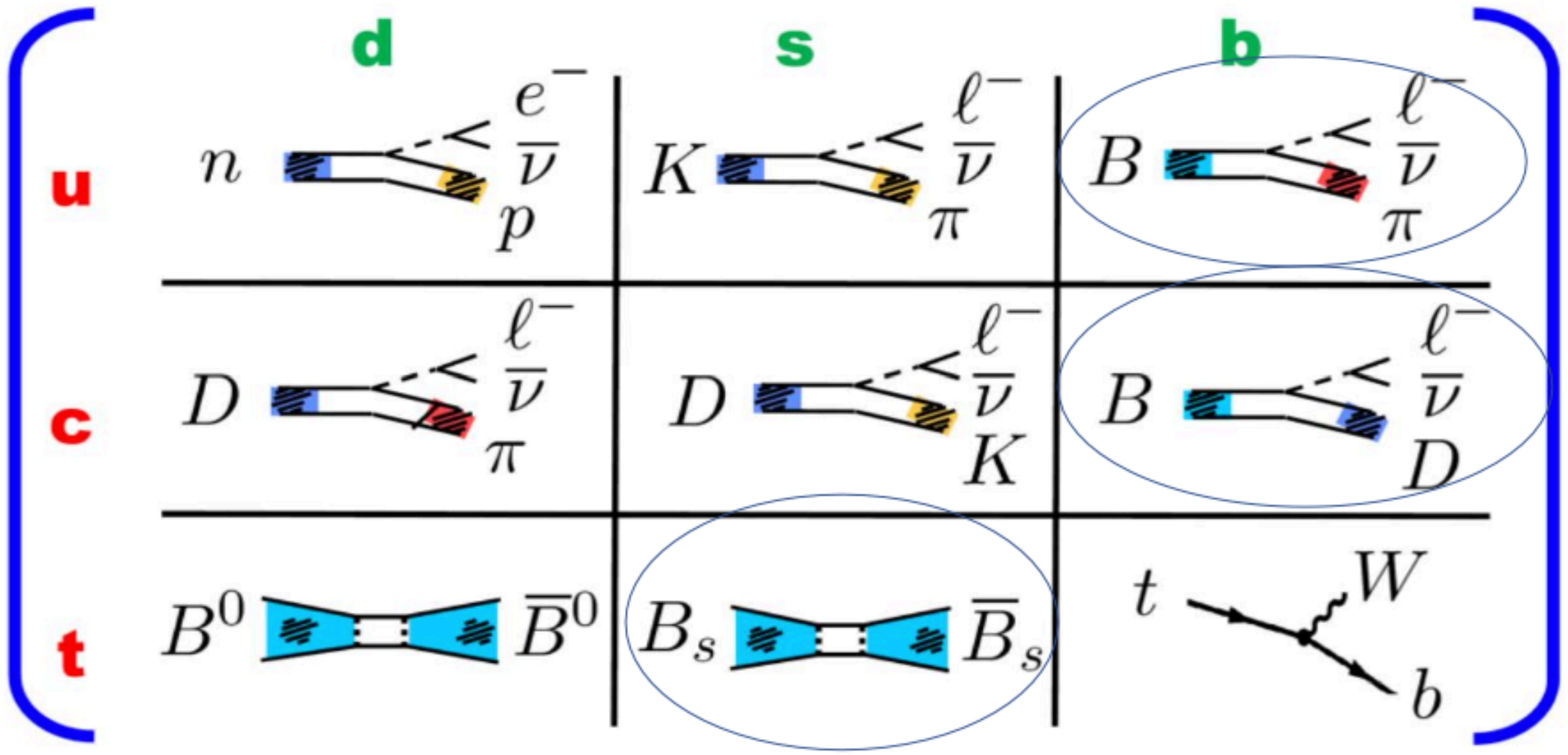
➡ Nucleons, K, D, $B_{(s)}$, and top quark physics

- **Unitarity triangle in the $(\bar{\rho}, \bar{\eta})$ complex plane**



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

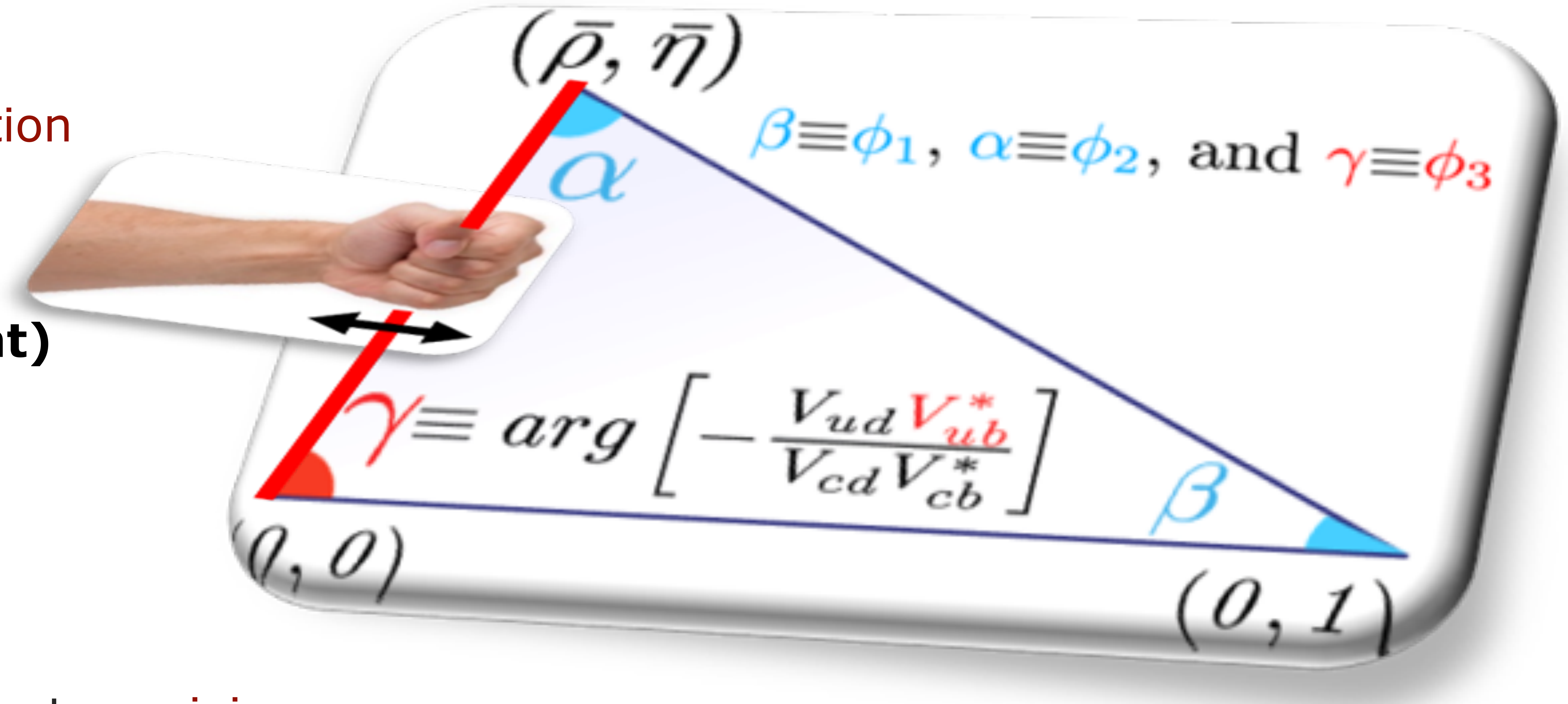
$V_{CKM} =$



Physics motivation : CKM matrix and unitary conditions

- In order to verify the unitarity of the CKM matrix

➡ Complex phase $\gamma = arg(-V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$ which is a source of CP violation can be measured from the processes mediated



- Only angle easily accessible at **Tree-level (direct measurement)**
  - theoretically clean
  - **"Standard candle" of the Standard Model**
  - Interference between between b→c and b→u quark transitions

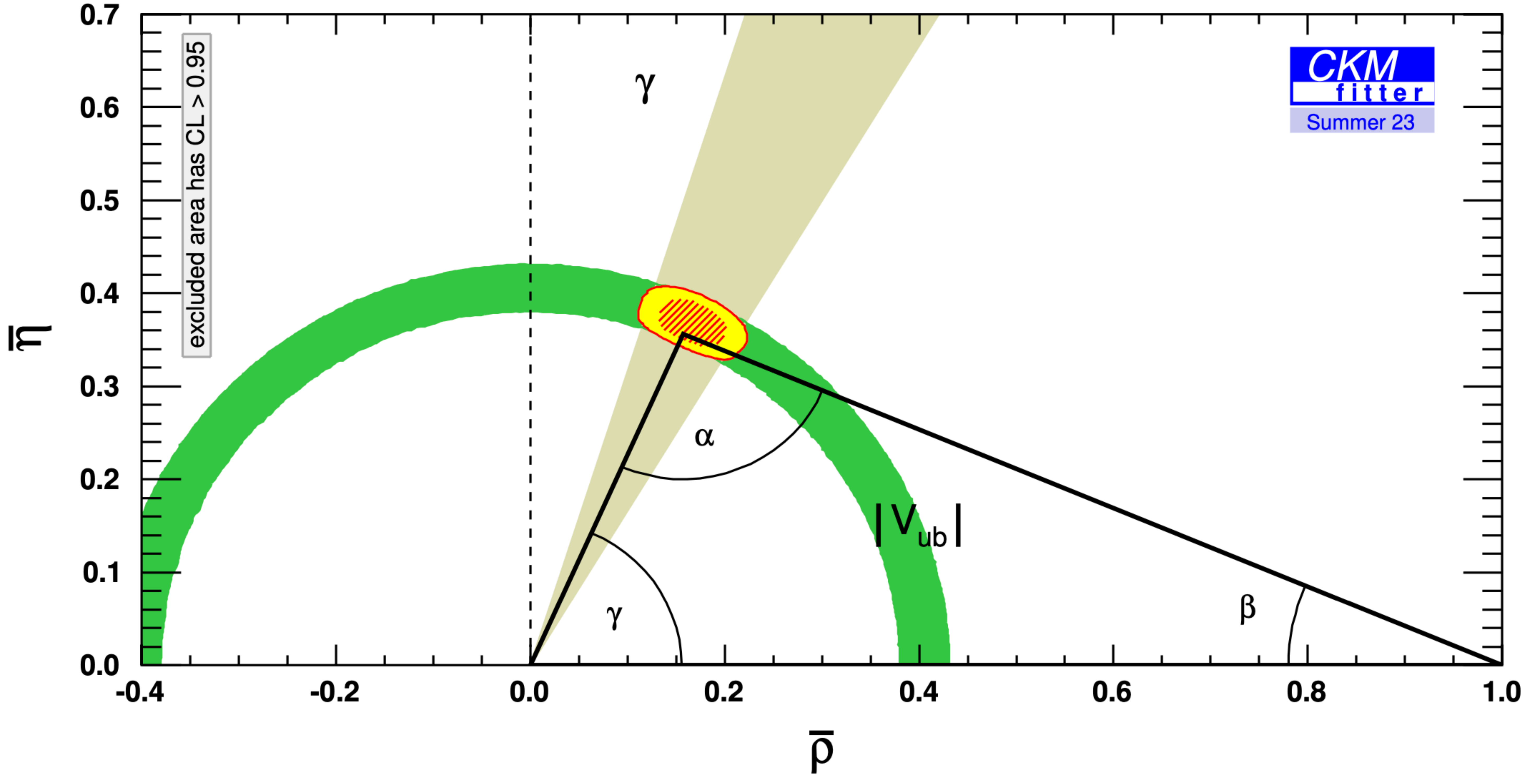
- Precise measurements of the magnitudes of the CKM matrix elements : mixing, branching fractions
- Sub-degree level of measurements to be compared with the CKMfitter global fit to challenge the Standard Model

- **Loop level (indirect measurement)**
  - **"sensitive to New Physics"**

Physics motivation : Unitarity triangle

http://ckmfitter.in2p3.fr/

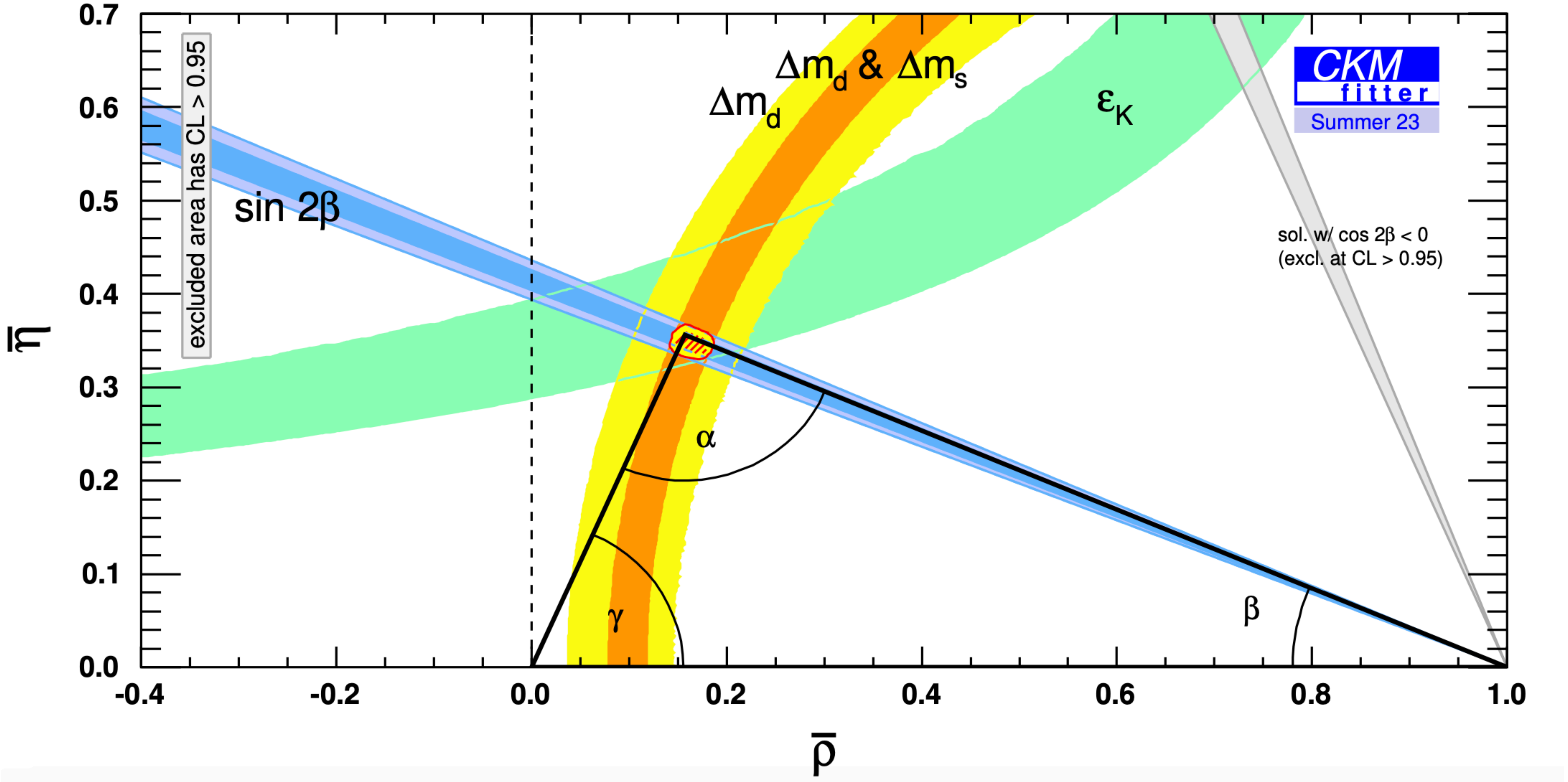
- Discrepancy between these will indicate "**New Physics**"
- Many different channels used to measure the angles and sides of the triangle



Direct measuments

(Pure SM like)

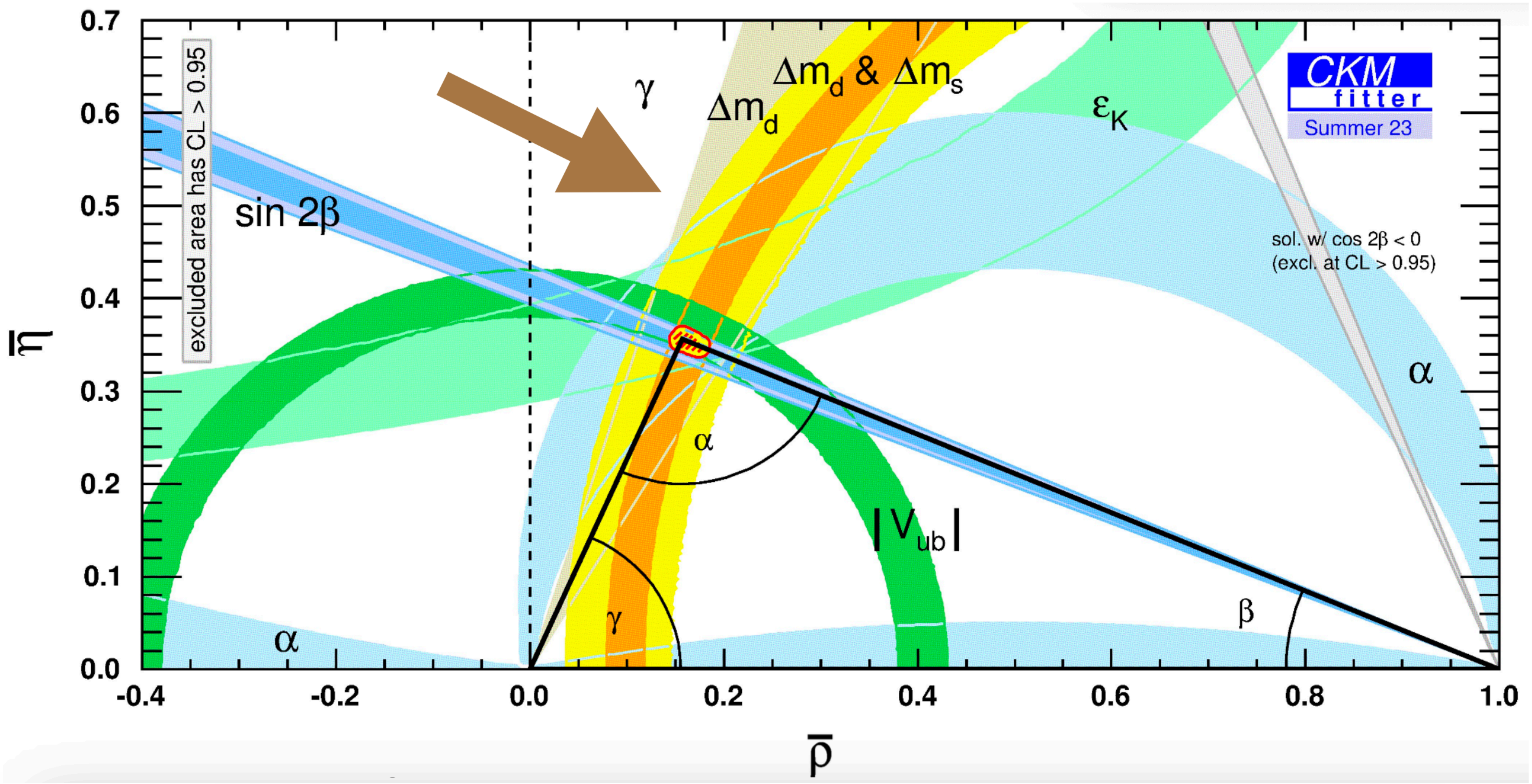
$$\gamma_{direct} = (66.4^{+2.8}_{-3.0})$$



Indirect measuments

(Possible sensitivity to NP)

$$\gamma_{indirect} = (66.3^{+0.72}_{-1.86})$$



LHCb-CONF-2024-004

Simultaneous determination of the CKM angle γ and parameters related to the mixing

✓ Measurements are performed from the analysis of Beauty and charm sectors which are sensitive to γ and charm mixing parameters

✓ Analysis based on data samples Run1+Run2 corresponding to an integrated luminosity of $9fb^{-1}$

Combination of CKM angle γ

NEW

LHCb-CONF-2024-004

➡ Inputs from beauty sector

B decay	D decay	Ref.	Dataset	Status since Ref. [14]
$B^\pm \to Dh^\pm$	$D \to h^\pm h'^\mp$	[35]	Run 1&2	*As before*
$B^\pm \to Dh^\pm$	$D \to h^+h^-\pi^+\pi^-$	[19]	Run 1&2	**New**
$B^\pm \to Dh^\pm$	$D \to K^\pm\pi^\mp\pi^+\pi^-$	[36]	Run 1&2	*As before*
$B^\pm \to Dh^\pm$	$D \to h^\pm h'^\mp \pi^0$	[37]	Run 1&2	*As before*
$B^\pm \to Dh^\pm$	$D \to K^0_S h^+h^-$	[38]	Run 1&2	*As before*
$B^\pm \to Dh^\pm$	$D \to K^0_S K^\pm\pi^\mp$	[39]	Run 1&2	*As before*
$B^\pm \to D^*h^\pm$	$D \to h^\pm h'^\mp$ (PR)	[35]	Run 1&2	*As before*
$B^\pm \to D^*h^\pm$	$D \to K^0_S h^+h^-$ (PR)	[20]	Run 1&2	**New**
$B^\pm \to D^*h^\pm$	$D \to K^0_S h^+h^-$ (FR)	[21]	Run 1&2	**New**
$B^\pm \to DK^{*\pm}$	$D \to h^\pm h'^\mp$	[22]†	Run 1&2	**Updated**
$B^\pm \to DK^{*\pm}$	$D \to h^\pm\pi^\mp\pi^+\pi^-$	[22]†	Run 1&2	**Updated**
$B^\pm \to DK^{*\pm}$	$D \to K^0_S h^+h^-$	[22]†	Run 1&2	**New**
$B^\pm \to Dh^\pm\pi^+\pi^-$	$D \to h^\pm h'^\mp$	[40]	Run 1	*As before*
$B^0 \to DK^{*0}$	$D \to h^\pm h'^\mp$	[23]	Run 1&2	**Updated**
$B^0 \to DK^{*0}$	$D \to h^\pm\pi^\mp\pi^+\pi^-$	[23]	Run 1&2	**Updated**
$B^0 \to DK^{*0}$	$D \to K^0_S h^+h^-$	[24]	Run 1&2	**Updated**
$B^0 \to D^\mp\pi^\pm$	$D^+ \to K^-\pi^+\pi^+$	[41]	Run 1	*As before*
$B^0_s \to D_s^\mp K^\pm$	$D_s^+ \to h^+h^-\pi^+$	[25,42]†	Run 1&2	**Updated**
$B^0_s \to D_s^\mp K^\pm\pi^+\pi^-$	$D_s^+ \to h^+h^-\pi^+$	[43]	Run 1&2	*As before*

- Combination of measurements sensitive to CKM angle γ
- 198 observables to determine 53 free parameters with all frequentist treatment
- External inputs from BESIII and CLEO Collaborations

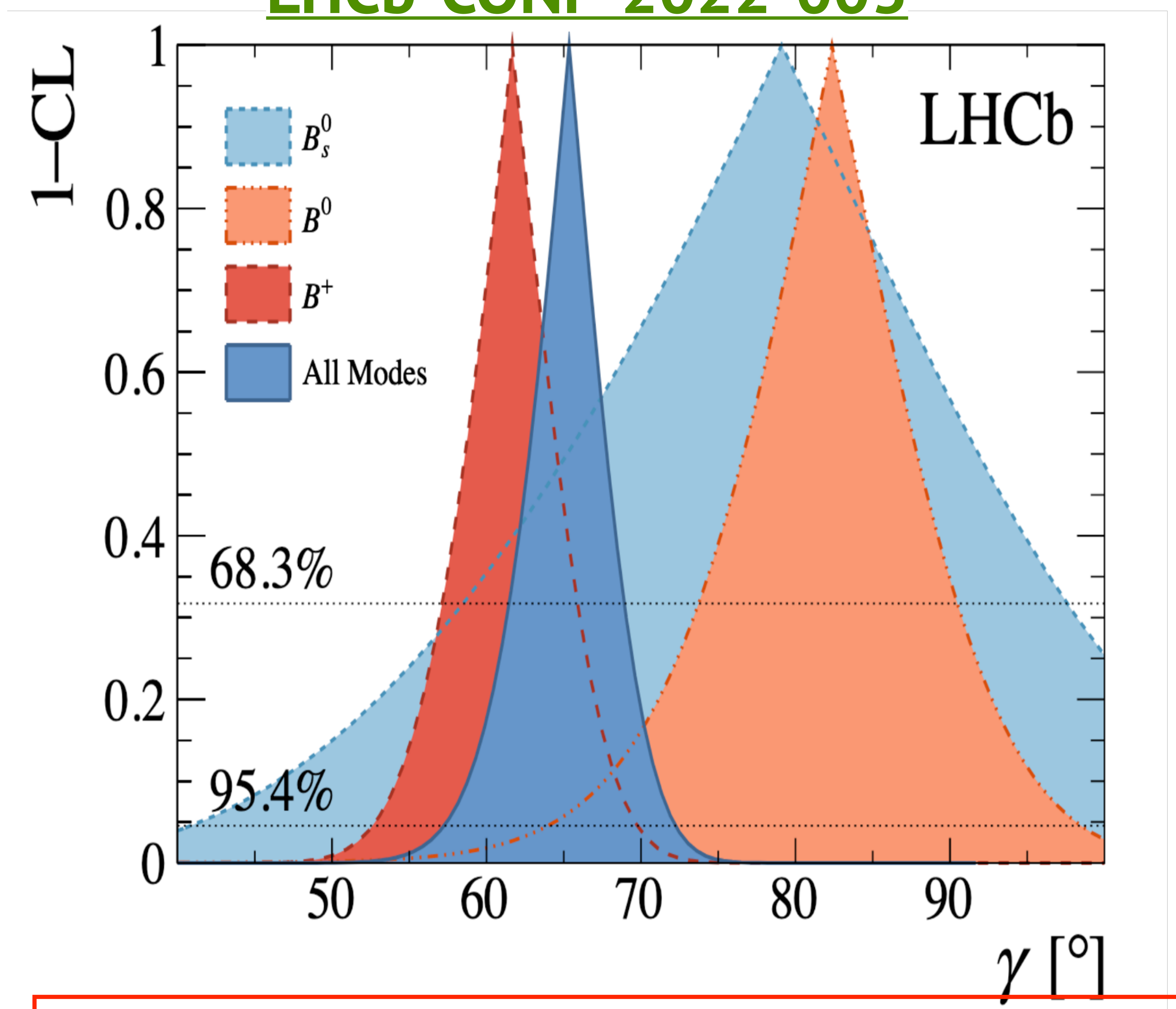
➡ Inputs from charm sector

D decay	Observable(s)	Ref.	Dataset	Status since Ref. [14]
$D^0 \to h^+h^-$	ΔA_{CP}	[44–46]	Run 1&2	*As before*
$D^0 \to K^+K^-$	$A_{CP}(K^+K^-)$	[46–48]	Run 2	*As before*
$D^0 \to h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	[49,50]	Run 1&2	*As before*
$D^0 \to h^+h^-$	ΔY	[51–54]	Run 1&2	*As before*
$D^0 \to K^+\pi^-$ (double tag)	$R^\pm$, $(x'^\pm)^2$, $y'^\pm$	[55]	Run 1	*As before*
$D^0 \to K^+\pi^-$ (single tag)	$R_{K\pi}$, $A_{K\pi}$, $c_{K\pi}^{(\prime)}$, $\Delta c_{K\pi}^{(\prime)}$	[27,56]	Run 1&2	**Updated**
$D^0 \to K^\pm\pi^\mp\pi^+\pi^-$	$(x^2+y^2)/4$	[57]	Run 1	*As before*
$D^0 \to K^0_S\pi^+\pi^-$	x, y	[58]	Run 1	*As before*
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[59]	Run 1	*As before*
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[60,61]	Run 2	*As before*
$D^0 \to \pi^+\pi^-\pi^0$	ΔY^{eff}	[26]	Run 2	**New**

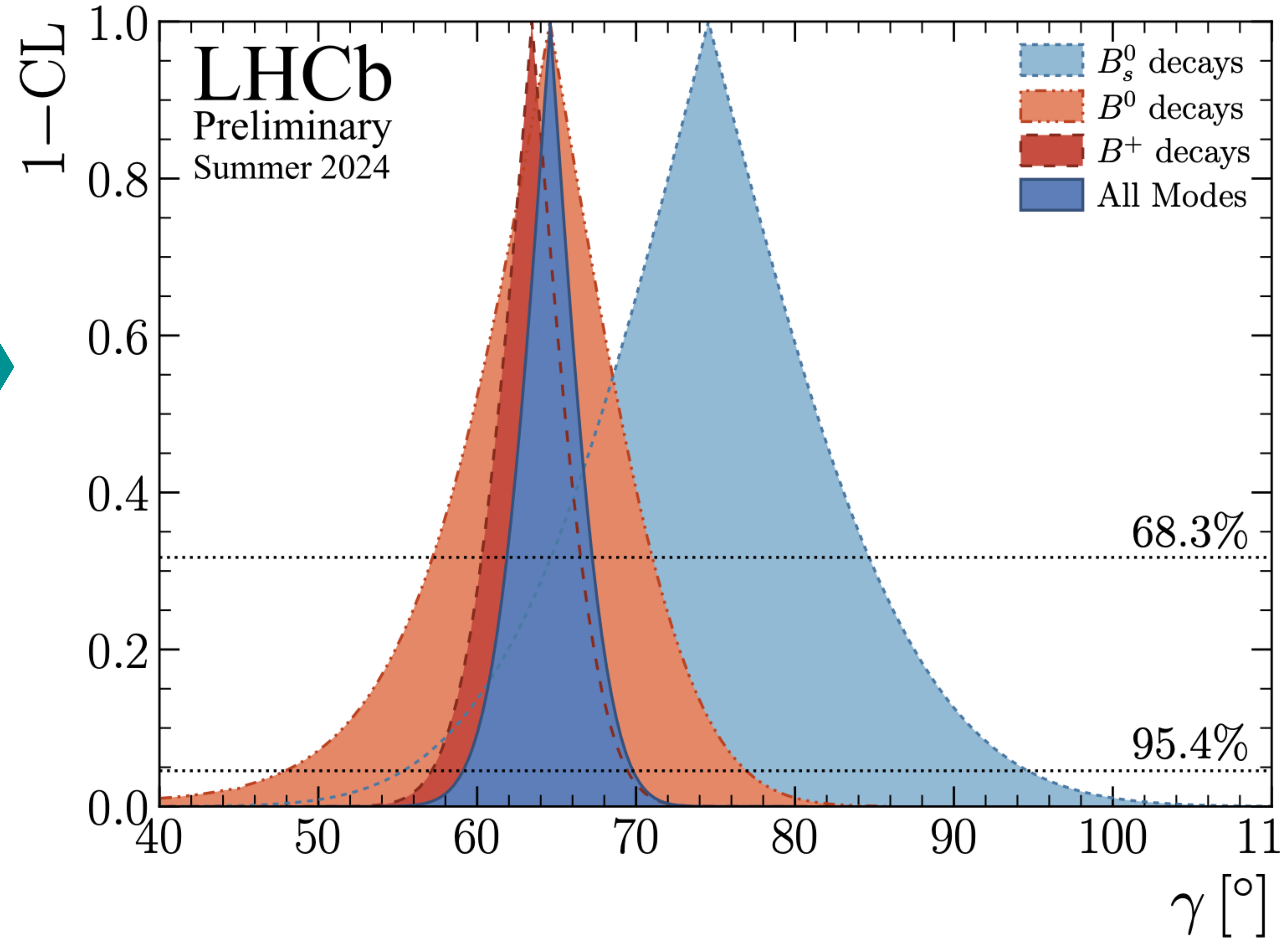
Combination of CKM angle γ

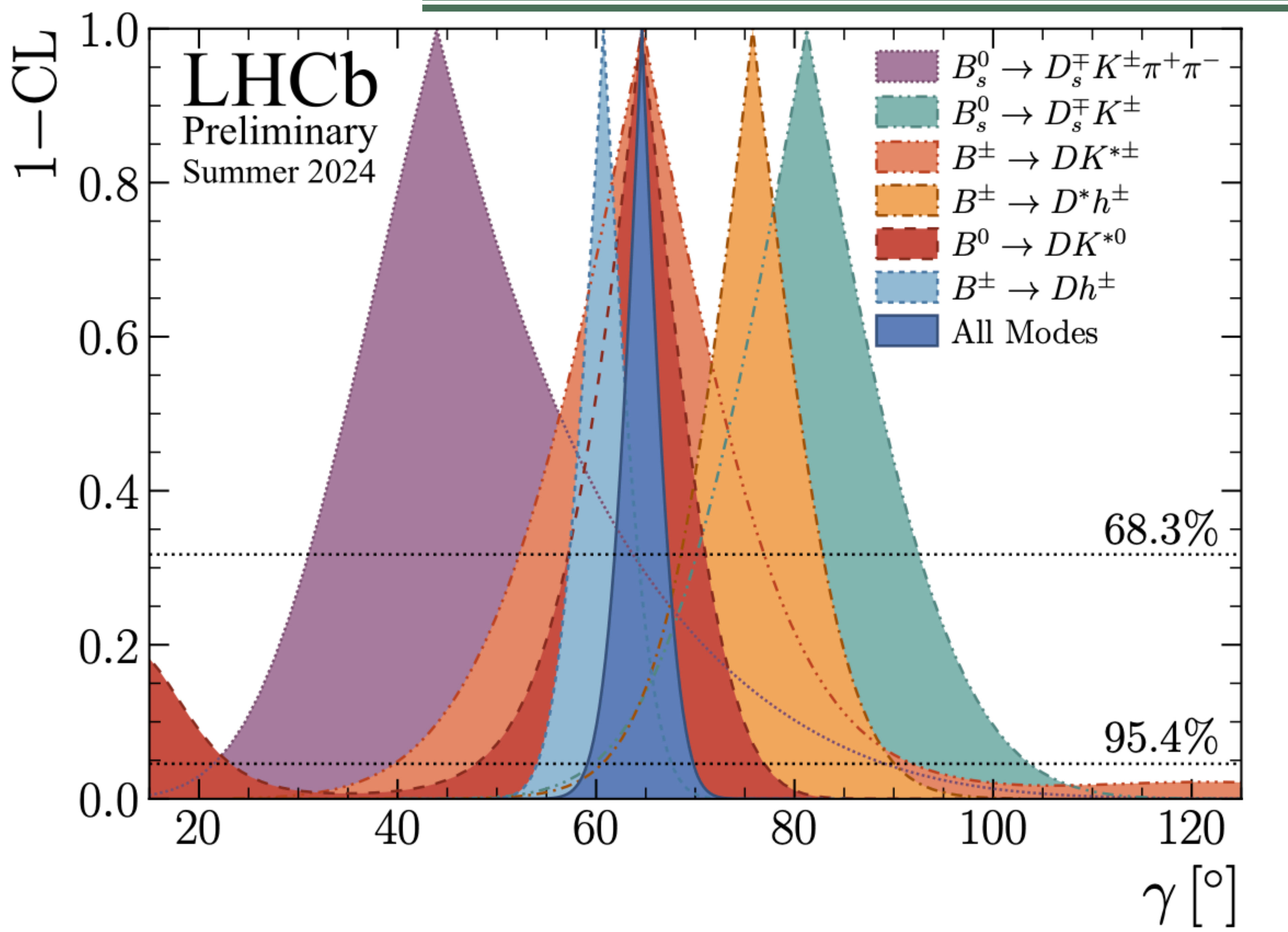
NEW

LHCb-CONF-2022-003



LHCb-CONF-2024-004





2022 LHCb average : $\gamma = (63.8^{+3.5}_{-3.7})$ ✓ **~1° more precise** **New LHCb average** : $\gamma = (64.6 \pm 2.8)°$

✦ The most precise determination of γ from a single experiment to date!

✦ Compatible with the previous LHCb combination [LHCb-CONF-2022-003]

✦ Time-dependent and tagging $B_s^0 \to D_s^\mp K^\pm (\pi\pi)$ analysis used Run1 & Run2

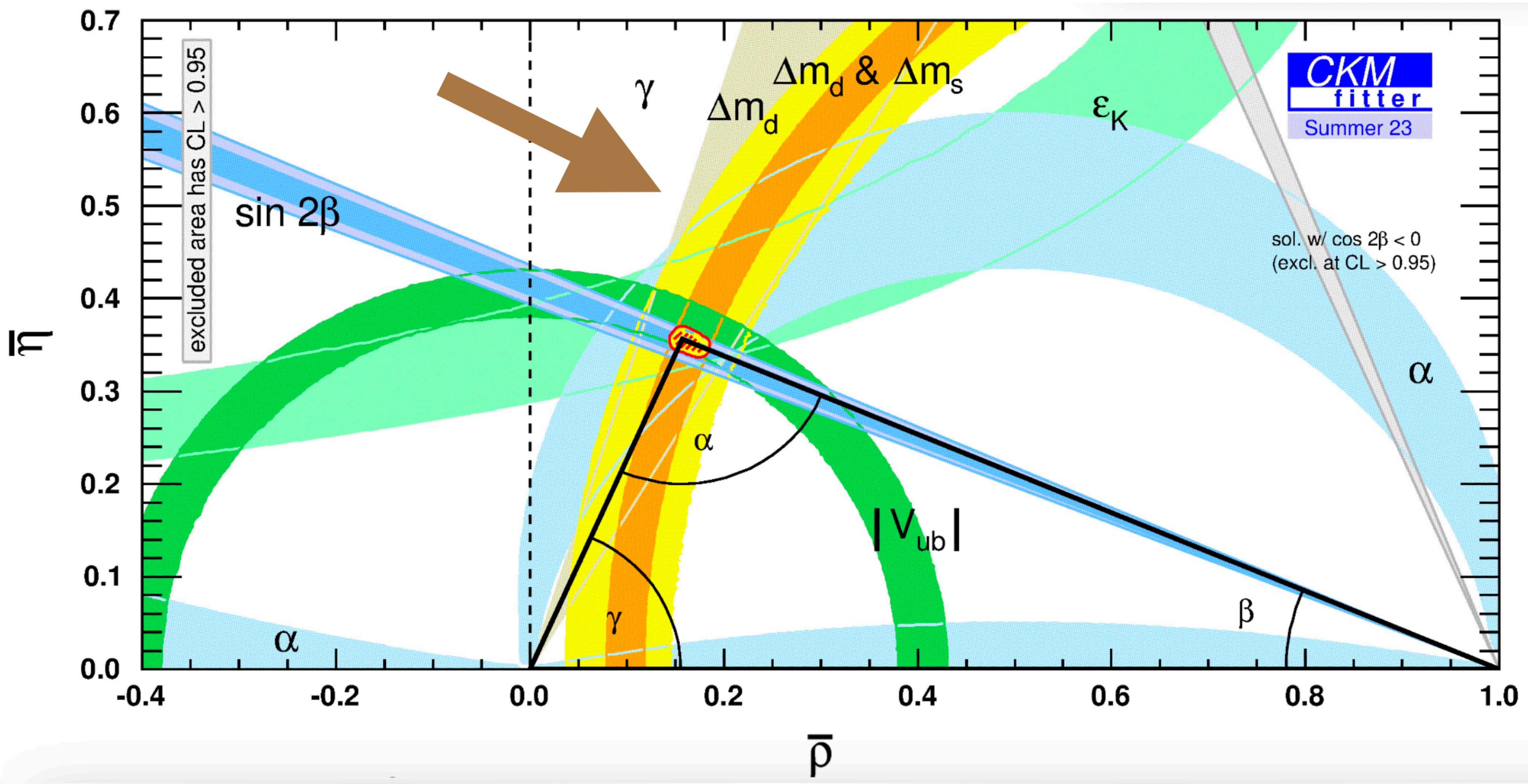
➡ constraint on γ~20° level of precision and the most probable values seems to be high uncertainty wrt the B^+ and B^0 measurements

✦ Tension between charged and neutral B mesons resolved

✦ **Coherence with**

$\gamma = (66.3^{+0.7}_{-1.9})°$
(**CKM fitter**, frequentist)

$\gamma = (64.9 \pm 1.4)°$
(**UTfit**, Bayesian)

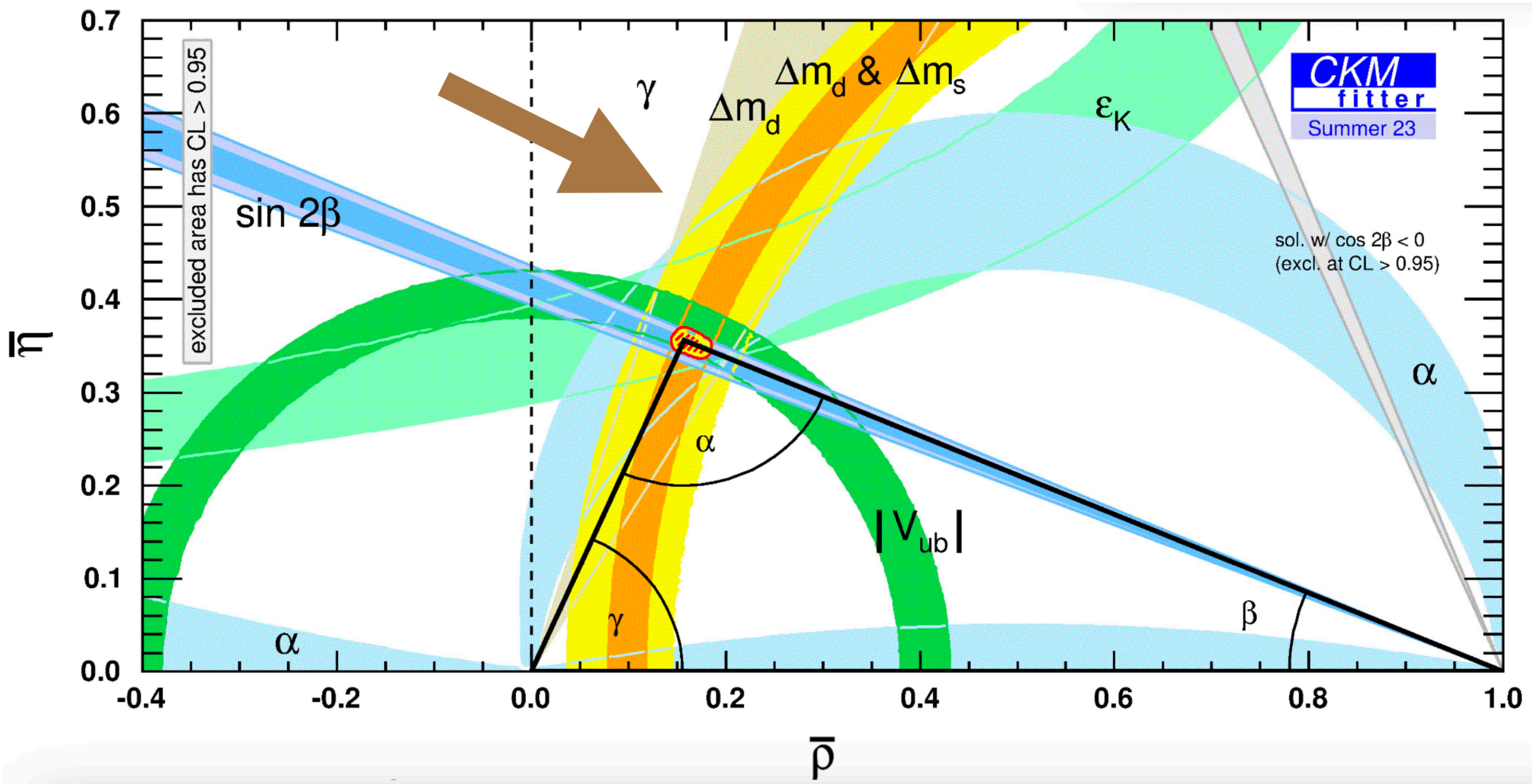


1 JHEP12(2023)013

2 JHEP02(2024)118

Measurements of the CKM angle γ using with $B^{\pm} \to D^{*}h^{\pm}$

- ✓ $B^{\pm} \to DK^{\pm}$ and $B^{\pm} \to D\pi^{\pm}$ are the golden modes to measure the CKM angle γ directly, where D meson can be reconstructed in different final states
- ✓ Final states need to be accessible to both D^0 and $\bar{D}^0$ to have an interference
- ✓ LHCb performed decays involving the excited D^* states which also offers good sensitivity
- ✓ LHCb are performed analysis using $B^{\pm} \to D^{*}h^{\pm}$ ($h^{\pm}$ can be either kaon or pion), where D^* reconstructed through the decays of $D^* \to D\gamma$ and $D^* \to D\pi^0$ and $D \to K_S^0\pi^+\pi^-/D \to K_S^0K^+K^-$
- ✓ Two separate measurements with the same decay chain but different techniques
- ✓ Neutral (π^0 or γ) reconstructed or not



1 JHEP12(2023)013

Measurements of the CKM angle γ using (fully reconstructed) $B^{\pm} \to D^{*}h^{\pm}$ channels

✓A measurement of the CP-violating observables from $B^{\pm} \to D^{*}h^{\pm}$ ($h^{\pm}$ can be either kaon or pion), where D^{*} reconstructed through the decays of $D^{*} \to D\gamma$ and $D \to K_S^0\pi^+\pi^-/D \to K_S^0K^+K^-$

✓ Signal yields variation analysis across the D decay phase space

✓Analysis based on Run1+Run2 data samples corresponding to a total integrated luminosity of $9fb^{-1}$

Measurements of the CKM angle γ using $B^\pm \to D^* h^\pm$ channels

JHEP12(2023)013

- $B^\pm$ decays with $D^* \to D\pi^0/\gamma$ with all final states reconstructed :

  - $D \to K_S^0\pi^+\pi^-$

  - $D \to K_S^0K^+K^-$

- Reconstruction requirements on the neutral (π^0 or γ)

- In order to extract CP-observables, unbinned extended maximum likelihood-fit to the 2D invariant mass of $B \to m(Dh)$ and $m(D\pi^0/\gamma)$ in each categories ($B^\pm$, D^* decays, D decays, DP bins, etc.)

- The yields of $B^\pm$ in the i^{th} bin

$$N_i(B^\pm) = H^{B^\pm}[F_{\mp i} + (x_\pm^2 + y_\pm^2)F_i + 2\kappa\sqrt{F_iF_{-i}}(x_\pm c_i \mp y_\pm s_i)]$$

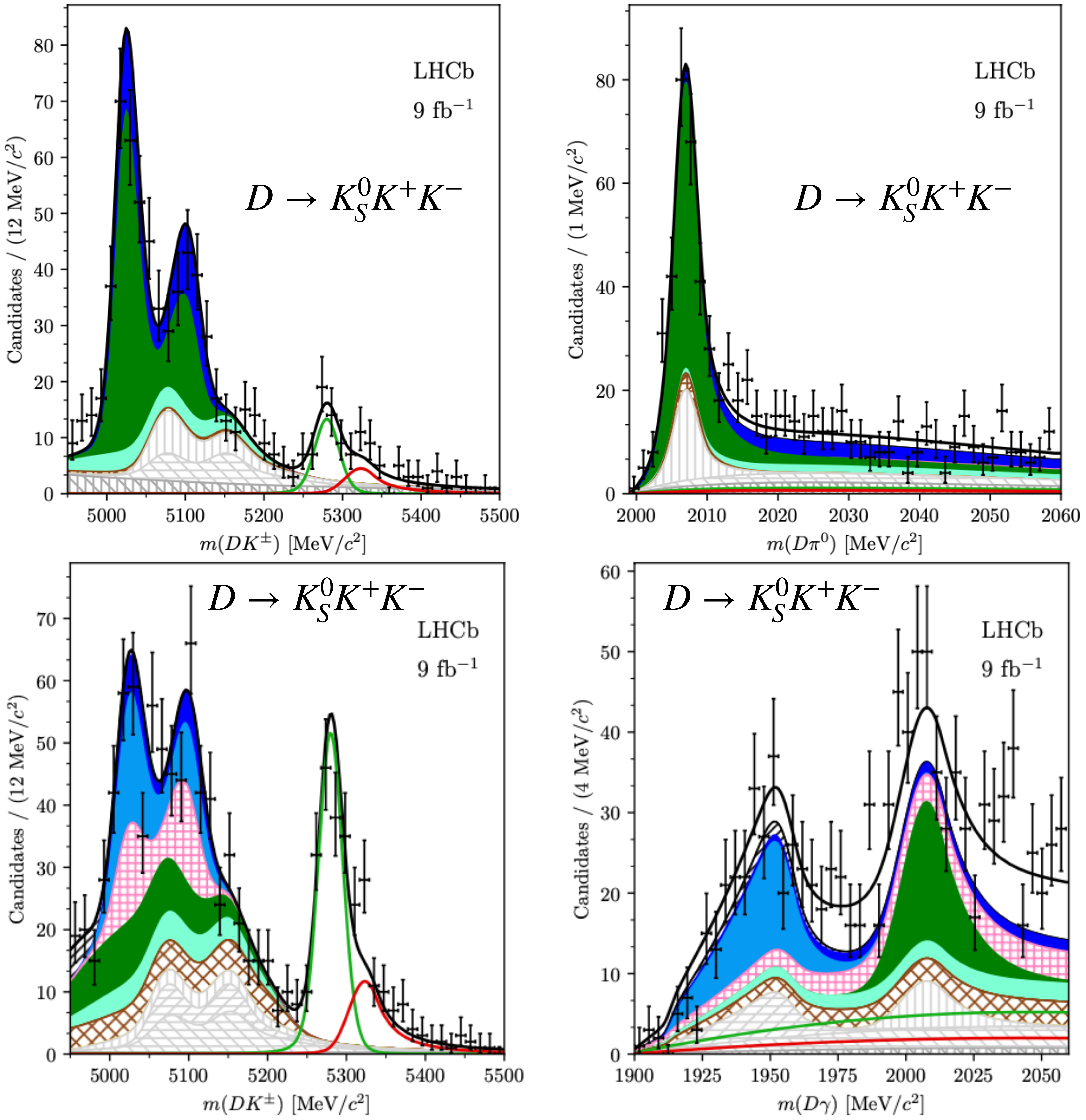
Normalization factor

Phase space probabilities

$\kappa_{B^0} \to DK^{*0} = 0.958^{+0.005}_{-0.046}$

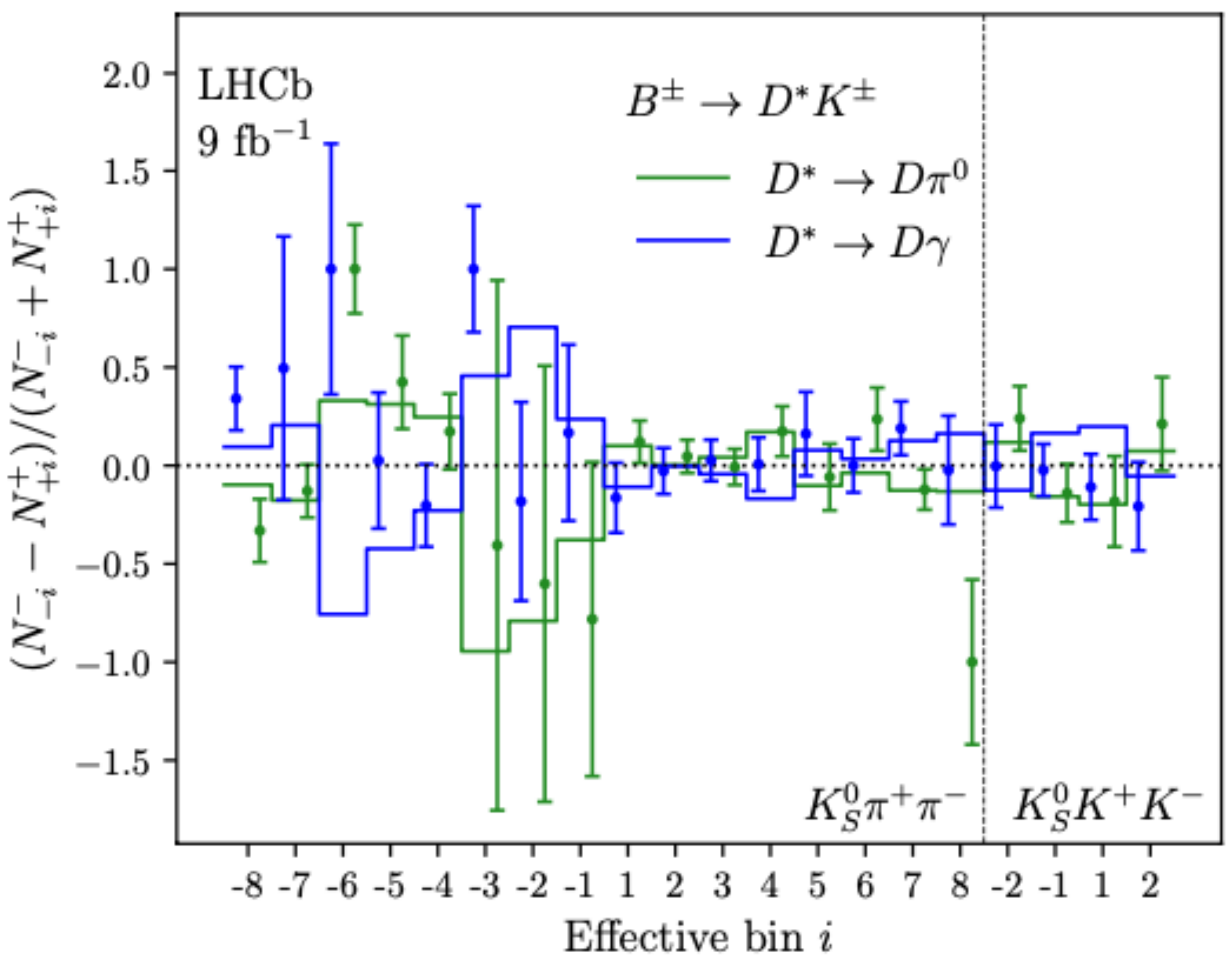
- External inputs c_i , s_i from the CLEO and BESIII Collaborations

- $F_{\pm i}$ determined via $B^\pm \to D^*\pi^\pm$



Measurements of the CKM angle γ using $B^\pm \to D^*h^\pm$ channels

JHEP12(2023)013

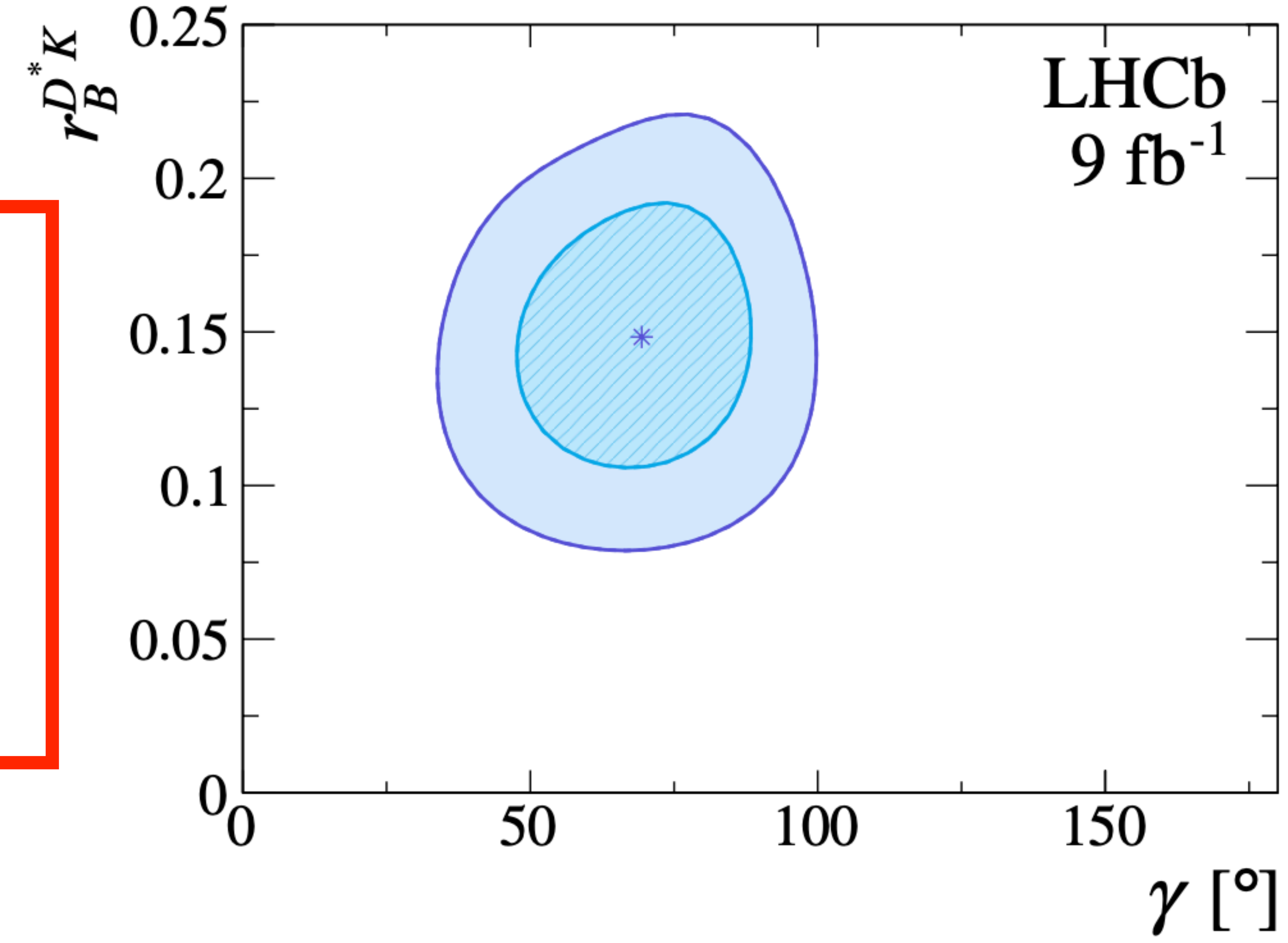


- Expected per bin asymmetry for $B^\pm \to D^*K^\pm$ and $B^\pm \to D^*\pi^\pm$ obtained by the CP-violating observables (solid lines) and obtained in fit with independent bin yields freely float (errors bars)
- Coherence between the individual bin asymmetries from the fit and the prediction from the CP-violating observables measured in the fit
- Bin asymmetries between $D^* \to D\gamma$ and $D^* \to D\pi^0$ are opposite in sign
  - Phase shift A(π^0)=-A(γ)
- The result of the CP-violating observables:

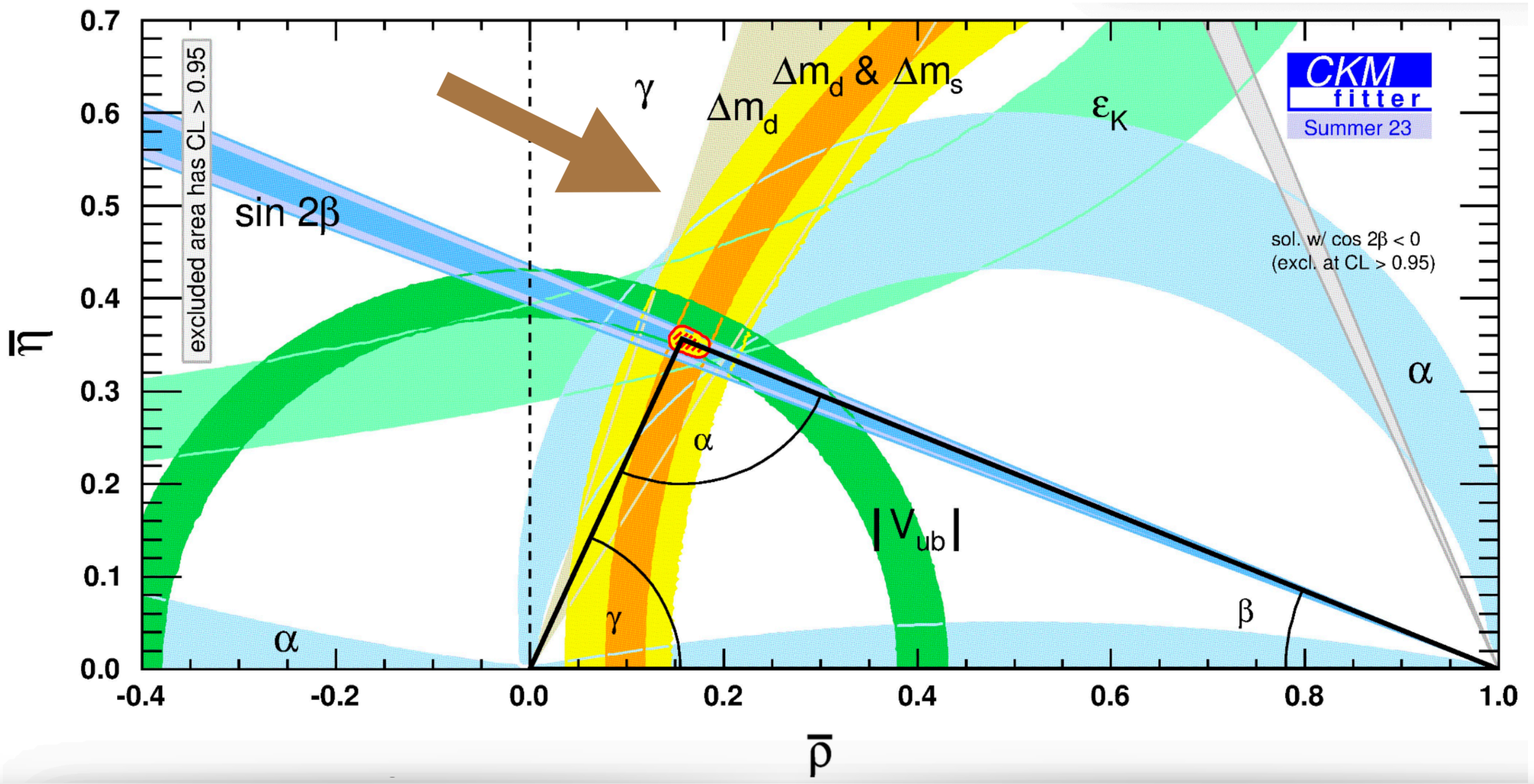
$$\gamma = (69^{+13}_{-14})^\circ$$

$$r_B^{D^*K} = 0.15 \pm 0.03$$

$$\delta_B^{D^*K} = (311 \pm 14)^\circ$$



- **Most precise determination of γ with these channels to date and provide good agreement with the world average!**



2 JHEP02(2024)118

A model independent measurement of the CKM angle γ in partially reconstructed $B^{\pm} \to D^{*}h^{\pm}$ decays with $D \to K_S^0 h^+ h^- (h = \pi, K)$

✓ First measurement at LHCb performed using partially reconstructed $B^{\pm} \to D^{*}h^{\pm}$ ($h^{\pm}$ can be either kaon or pion), where D^{*} reconstructed through the decays of $D^{*} \to D\gamma$

✓ Analysis based on Run1+Run2 data samples corresponding to an integrated luminosity of 9fb^{-1}

A model independent measurement of the CKM angle γ in partially reconstructed $B^{\pm} \to D^{*}h^{\pm}$

JHEP02(2024)118

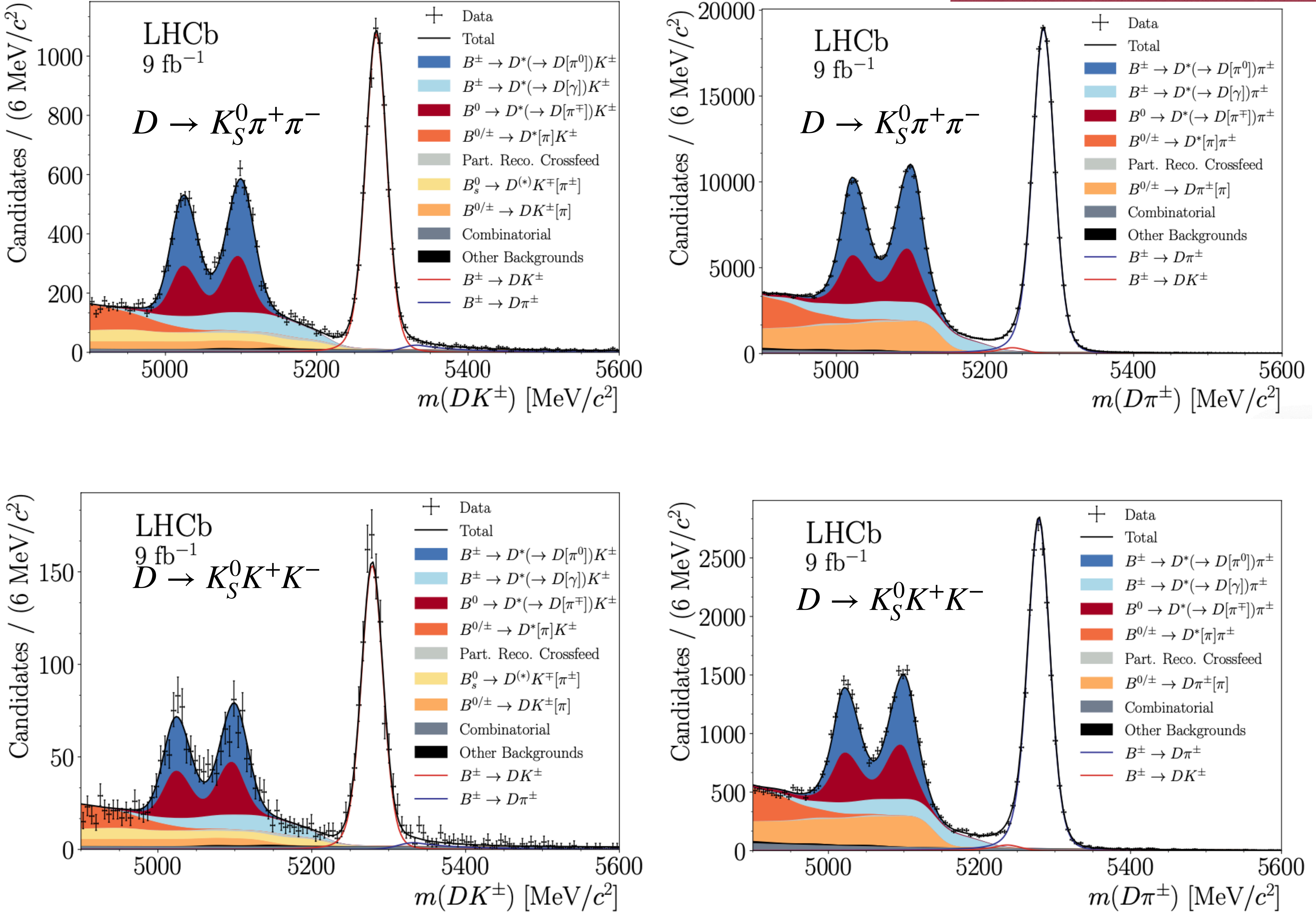
✦The D-meson reconstructed in the self-conjugate modes:

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

✦ $B^{\pm} \to [D\gamma/\pi^0]h^{\pm}$ with partial reconstruction of D^* and $D \to K_S^0h^+h^-$

✦ No reconstruction requirements on the neutral (π^0 or γ)

✦Binned extended maximum likelihood-fit to the reconstructed mass $B \to m(Dh)$



A model independent measurement of the CKM angle γ in partially reconstructed $B^{\pm} \to D^{*}h^{\pm}$

JHEP02(2024)118

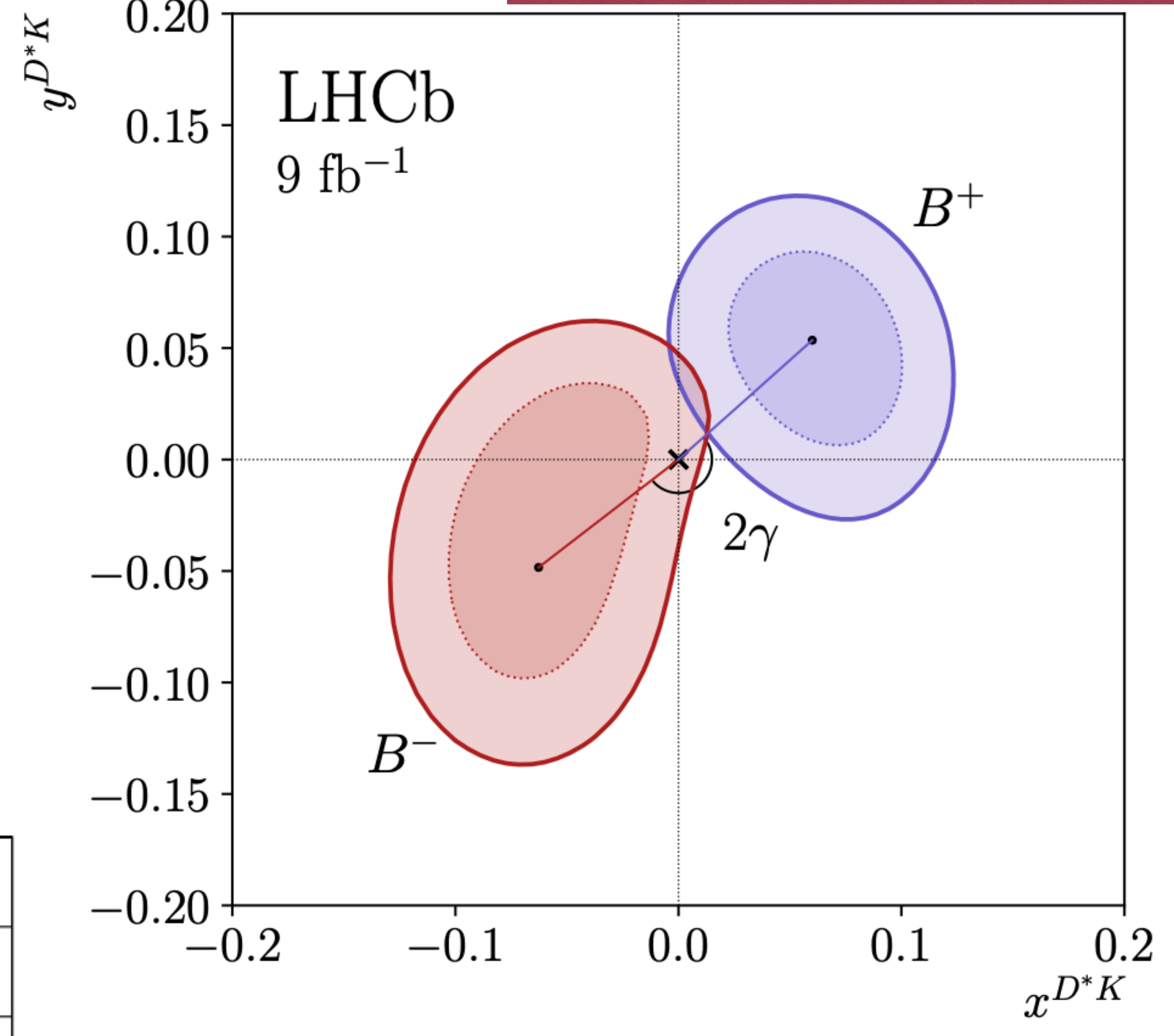
- ✦ The contribution to the uncertainty on γ statistically dominated
- ✦ Consistent with the LHCb γ combination! [LHCb-CONF-2022-003]

➡ Results interpreted in terms of :

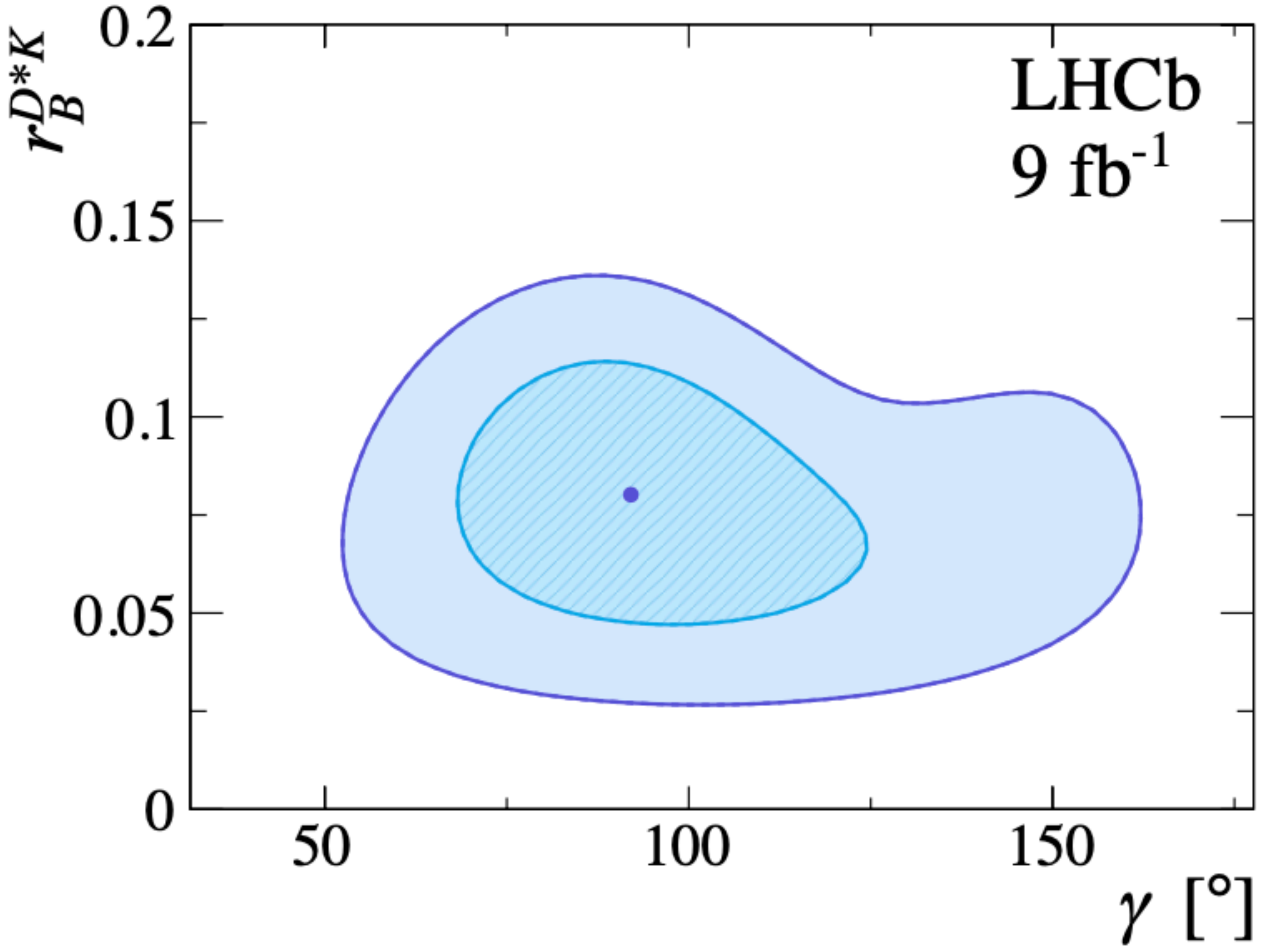
$$\gamma = (92^{+21}_{-17})^{\circ}$$

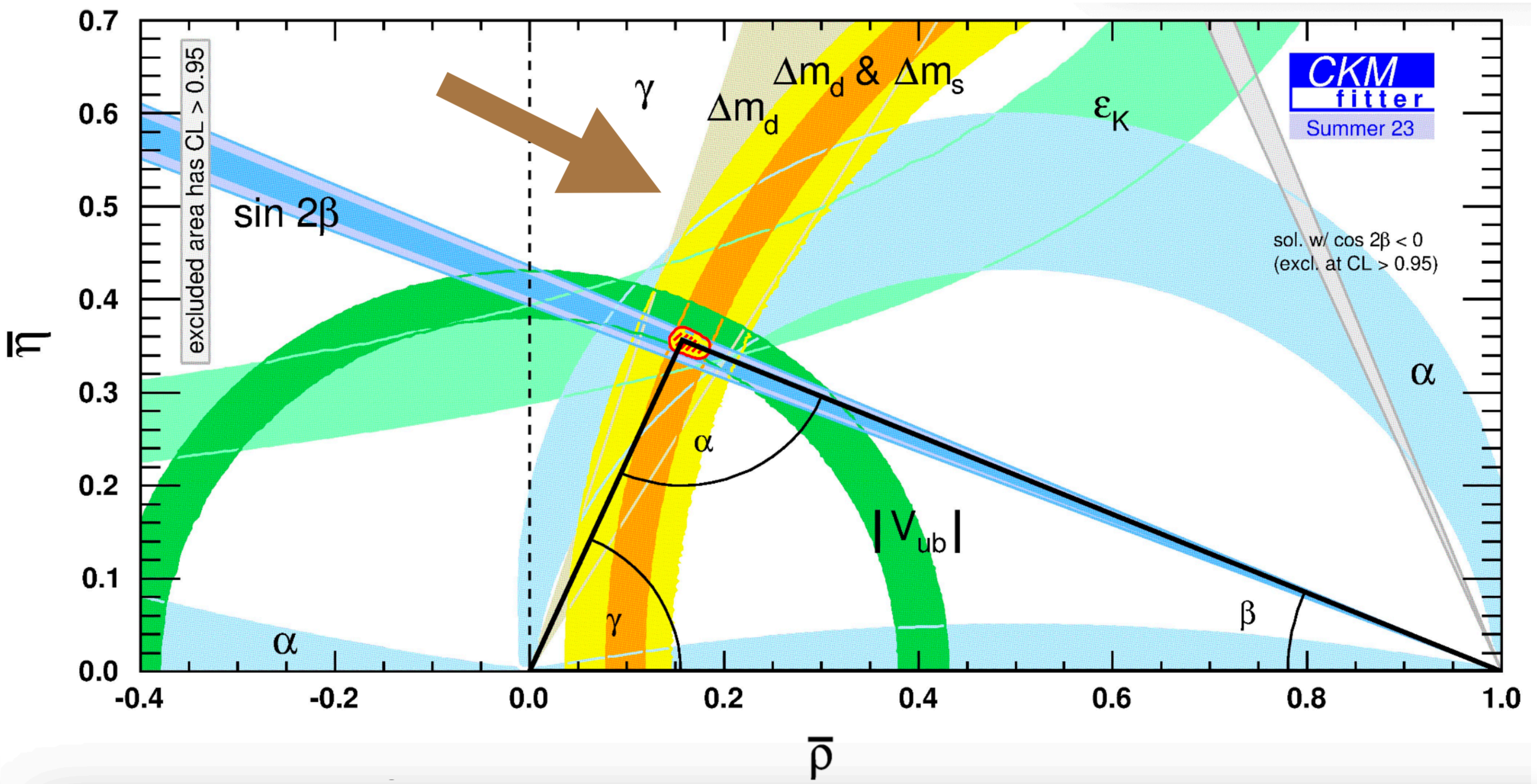
$$r_B^{D^*K} = 0.080^{+0.022}_{-0.023}$$

$$\delta_B^{D^*K} = (310^{+15}_{-20})^{\circ}$$



- ✦ Strong phase inputs from CLEO and BESIII experiments
- ✦ Results are consistent with the world average and those from other $B^{\pm} \to D^{*}h^{\pm}$ measurements
- ✦ Important to combine with the two- and four-body ADS/GLW modes in $B^{\pm} \to D^{*}h^{\pm}$ decays [JHEP04(2021)081]





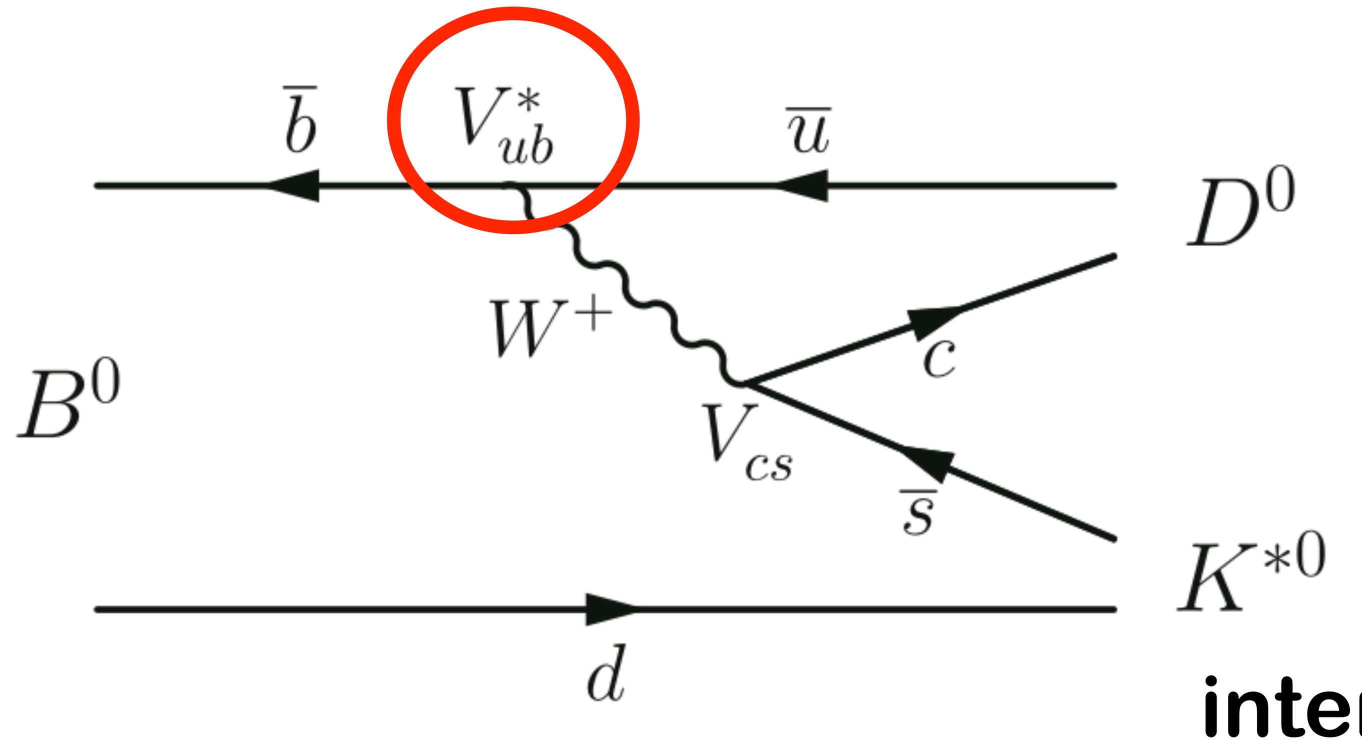
Eur. Phys. J. C 84 (2024) 206

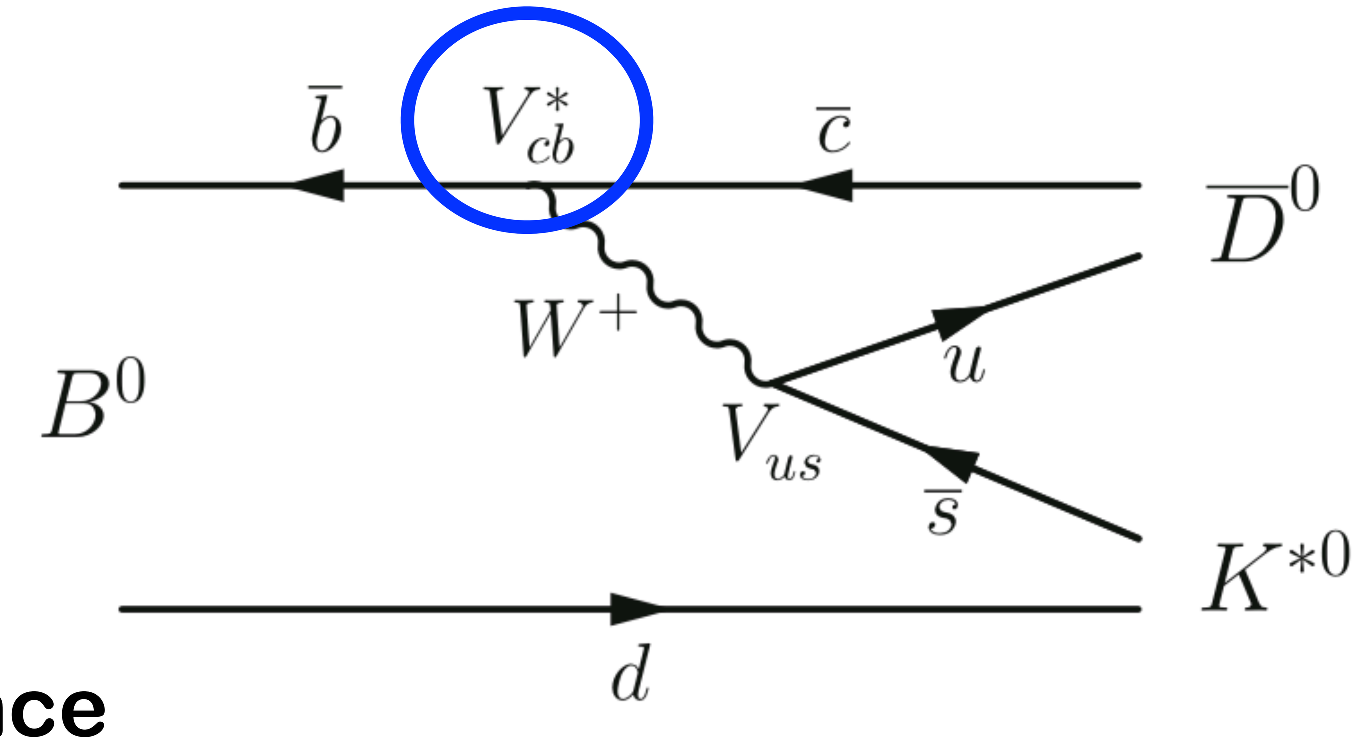
Measurement of the CKM angle γ in the $B^0 \to DK^{*0}$ channel using self-conjugate $D \to K_S^0 h^+ h^-$ decays

✓ Measurements are performed from a model independent study of CP violation in $B^0 \to DK^{*0}$ decays

✓ The $K^*(892)^0$ meson is referred as K^{*0}, where decays to $K^+\pi^-$

✓ Analysis based on Run1+Run2 data samples corresponding to an integrated luminosity of 9fb^{-1}



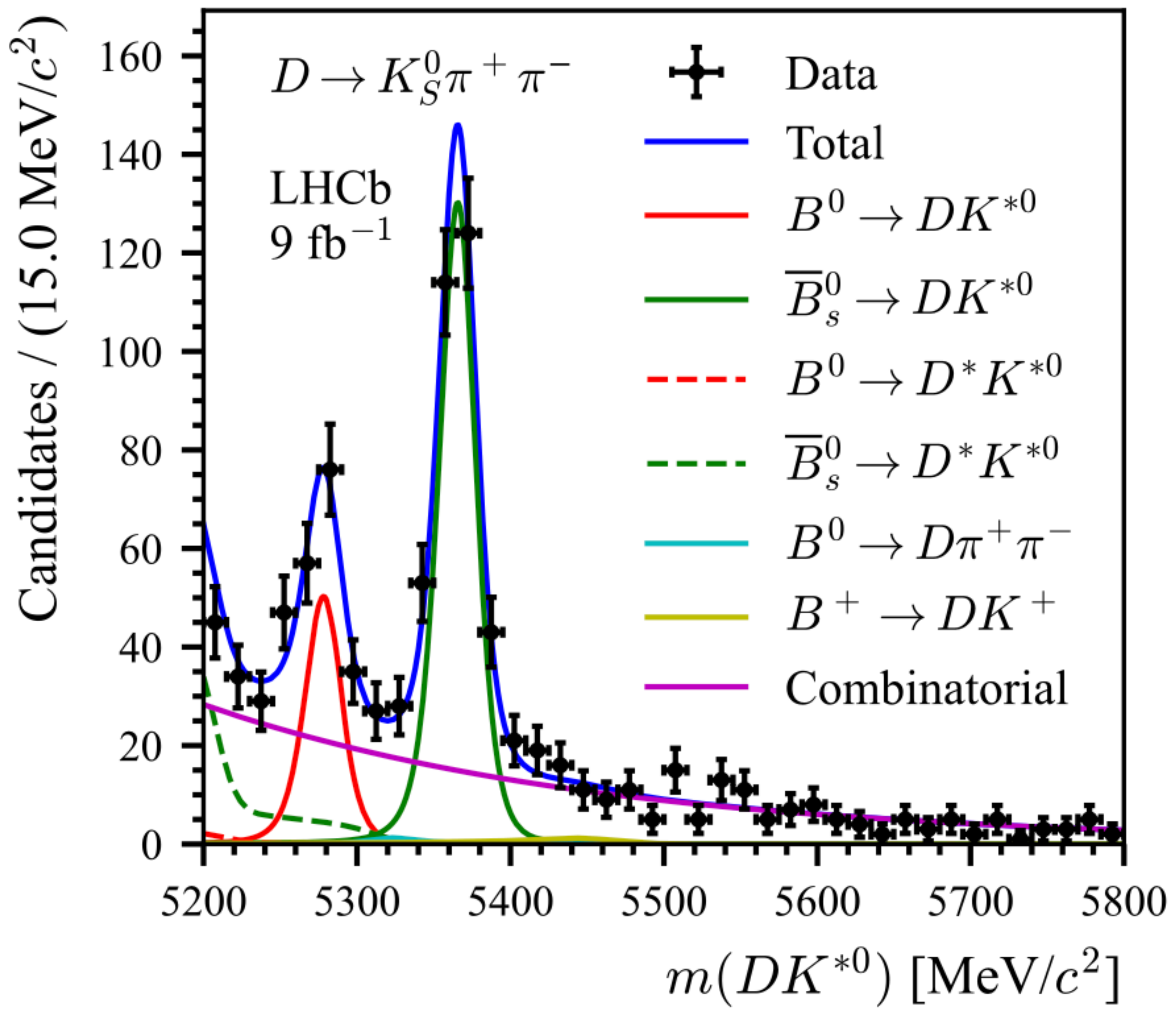


interference

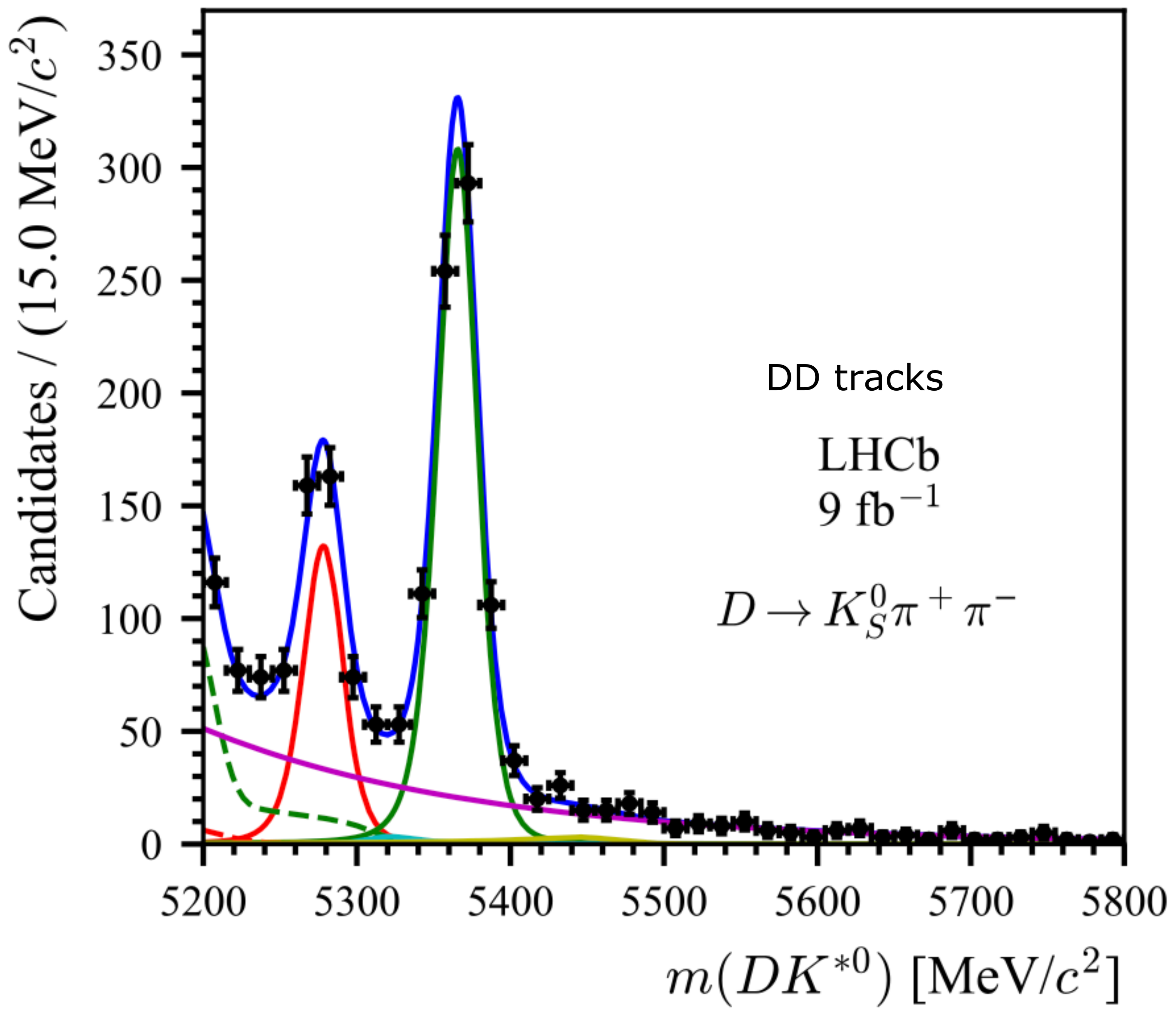
Measurement of the CKM angle γ in the $B^0 \to DK^{*0}$ channel using self-conjugate $D \to K^0_S h^+ h^-$ decays

Eur. Phys. J. C 84 (2024) 206

- The D-meson reconstructed in the self-conjugate decays:
  - $D \to K^0_S \pi^+ \pi^-$
  - $D \to K^0_S K^+ K^-$
- Binned fit in phase space of $D \to K^0_S h^+ h^-$
- The separation is based on the K_S decays to $\pi\pi$ within VELO or outside for long and downstream, respectively
- **The 2/3rd of the statistics is from DD types events**
- The BR of the $B^0 \to DK^*(892)^0$ BR is lower than $B^\pm \to DK^\pm$ but has larger interference $\sim 3 r_{B^\pm}$



LL tracks: K^0_S decays in the VELO



DD tracks: K^0_S decays downstream of VELO

- The yields of B^0 and $\bar{B}^0$ decays in a Dalitz plot bin

$$N_i(B^0) = h^{B^0}[F_{-i} + (x_+^2 + y_+^2)F_i + 2\kappa\sqrt{F_i F_{-i}}(x_+ c_i - y_+ s_i)]$$

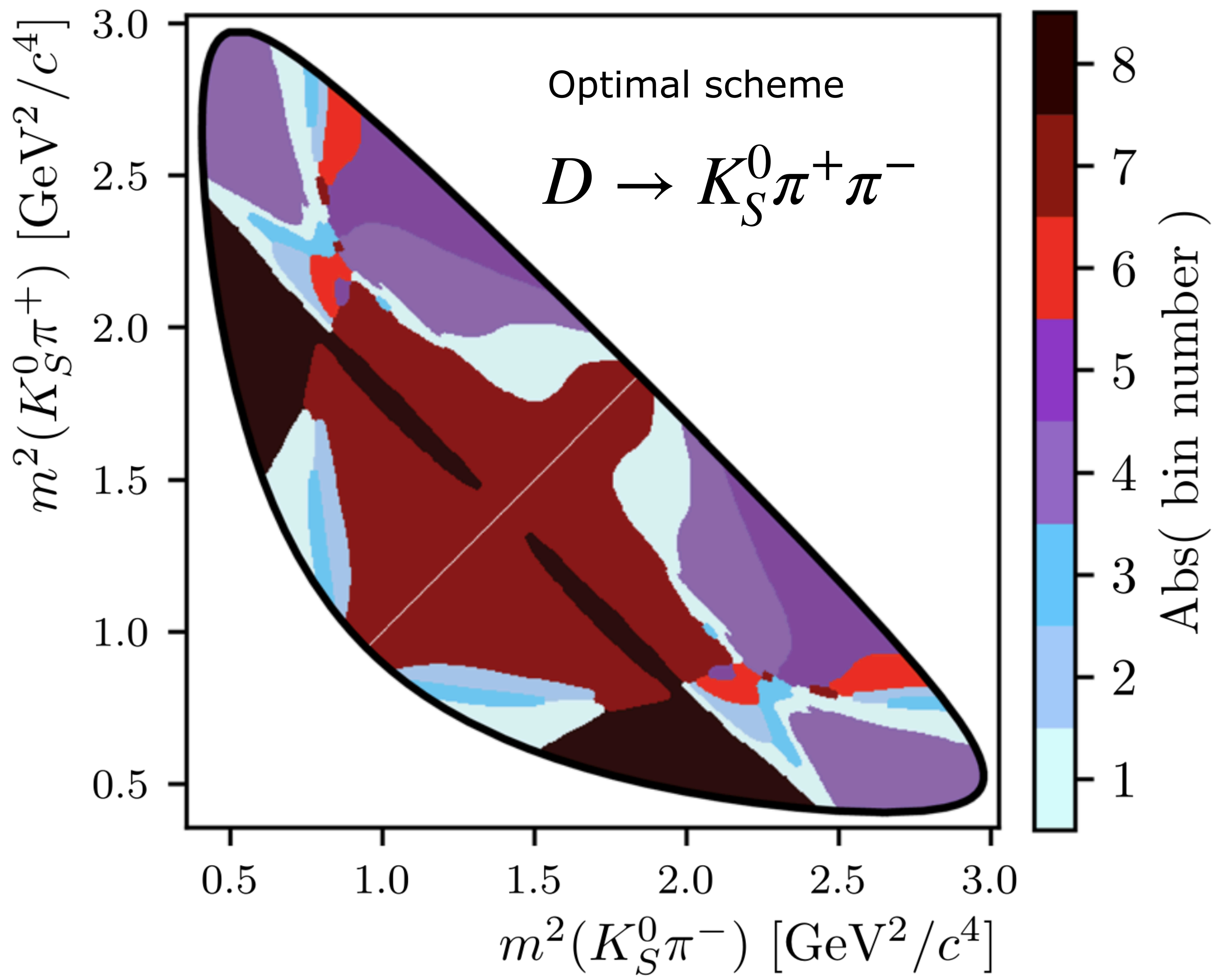
$$N_i(\bar{B}^0) = h^{\bar{B}^0}[F_i + (x_-^2 + y_-^2)F_{-i} + 2\kappa\sqrt{F_i F_{-i}}(x_- c_i + y_+ s_i)]$$

Normalization factor

Phase space probabilities

$\kappa_{B^0} \to DK^{*0} = 0.958^{+0.005}_{-0.046}$

- Dalitz plot binning scheme used for $D \to K^0_S \pi^+ \pi^-$



- The external input parameters $\kappa, F_{\pm i}, c_i, s_i$ are fixed to their central values in the fit.

Measurement of the CKM angle γ in the $B^0 \to DK^{*0}$ channel using self-conjugate $D \to K_S^0 h^+ h^-$ decays

Eur. Phys. J. C 84 (2024) 206

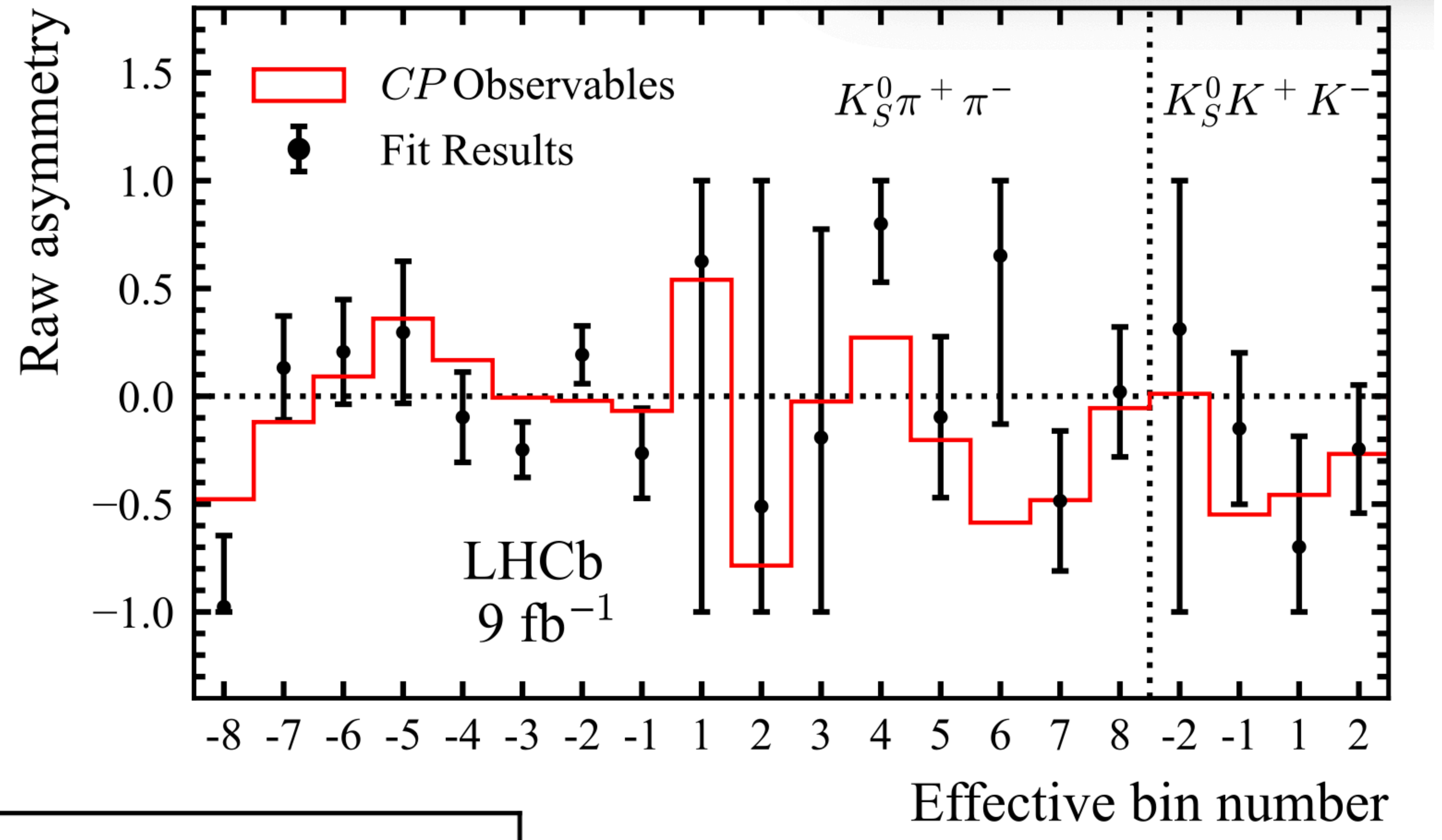
✦ Simultaneous binned fit to extract the CP observables :

$$x_\pm \equiv r_{B^0}^{DK^*} cos(\Delta\delta_{B^0}^{DK^*} \pm \gamma)$$
$$y_\pm \equiv r_{B^0}^{DK^*} sin(\Delta\delta_{B^0}^{DK^*} \pm \gamma)$$

$$\delta_B^{D^*K} = (236^{+19}_{-21})°$$

$$r_B^{D^*K} = 0.271^{+0.065}_{-0.066}$$

$$\gamma = (49^{+22}_{-19})°$$



✦ Combined values shows consistency with the LHCb γ combination average! [LHCb-CONF-2024-004]

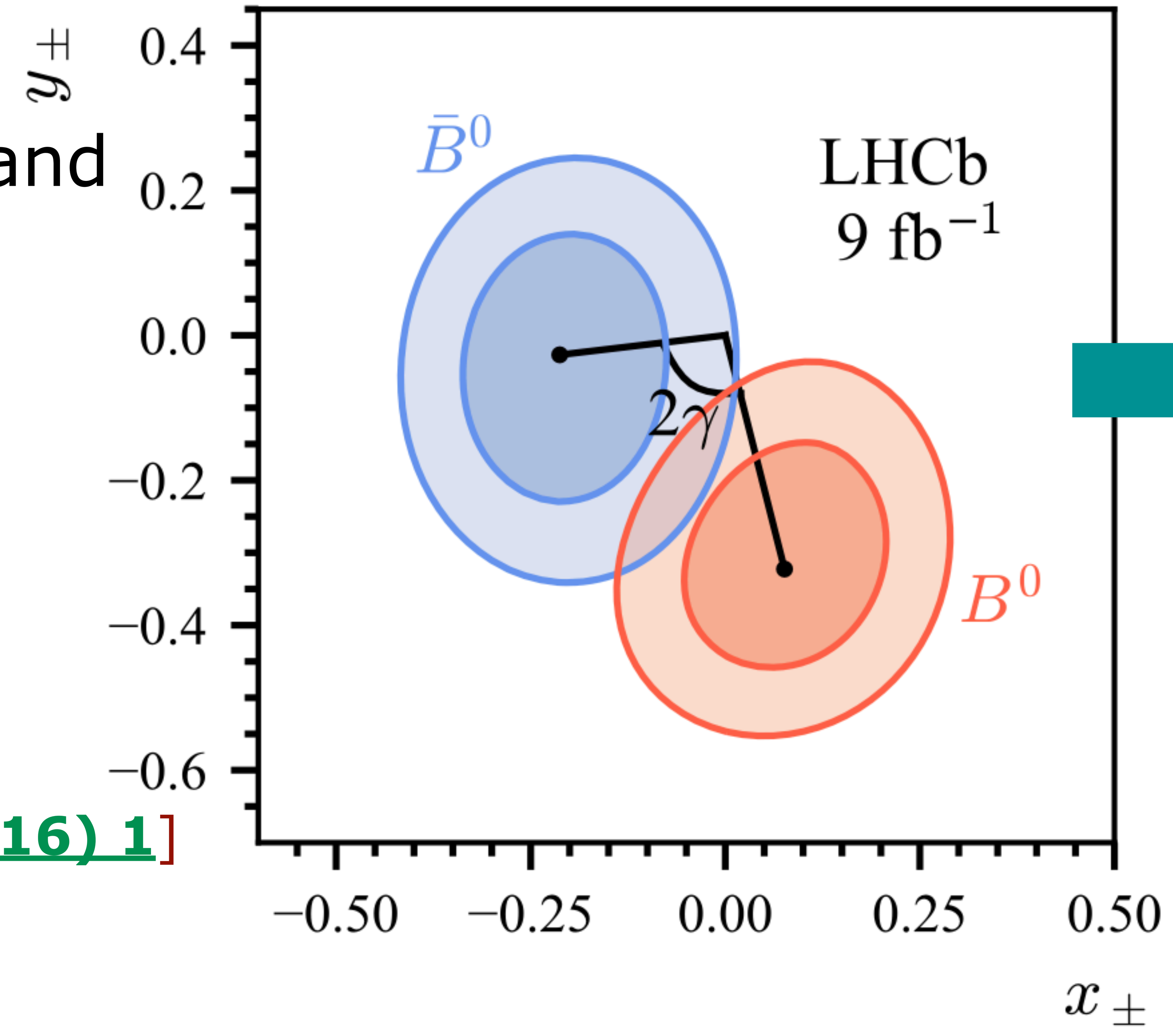
✦ External strong phase inputs of $D \to K_S^0 h^+ h^-$ from CLEO and BESIII collaborations

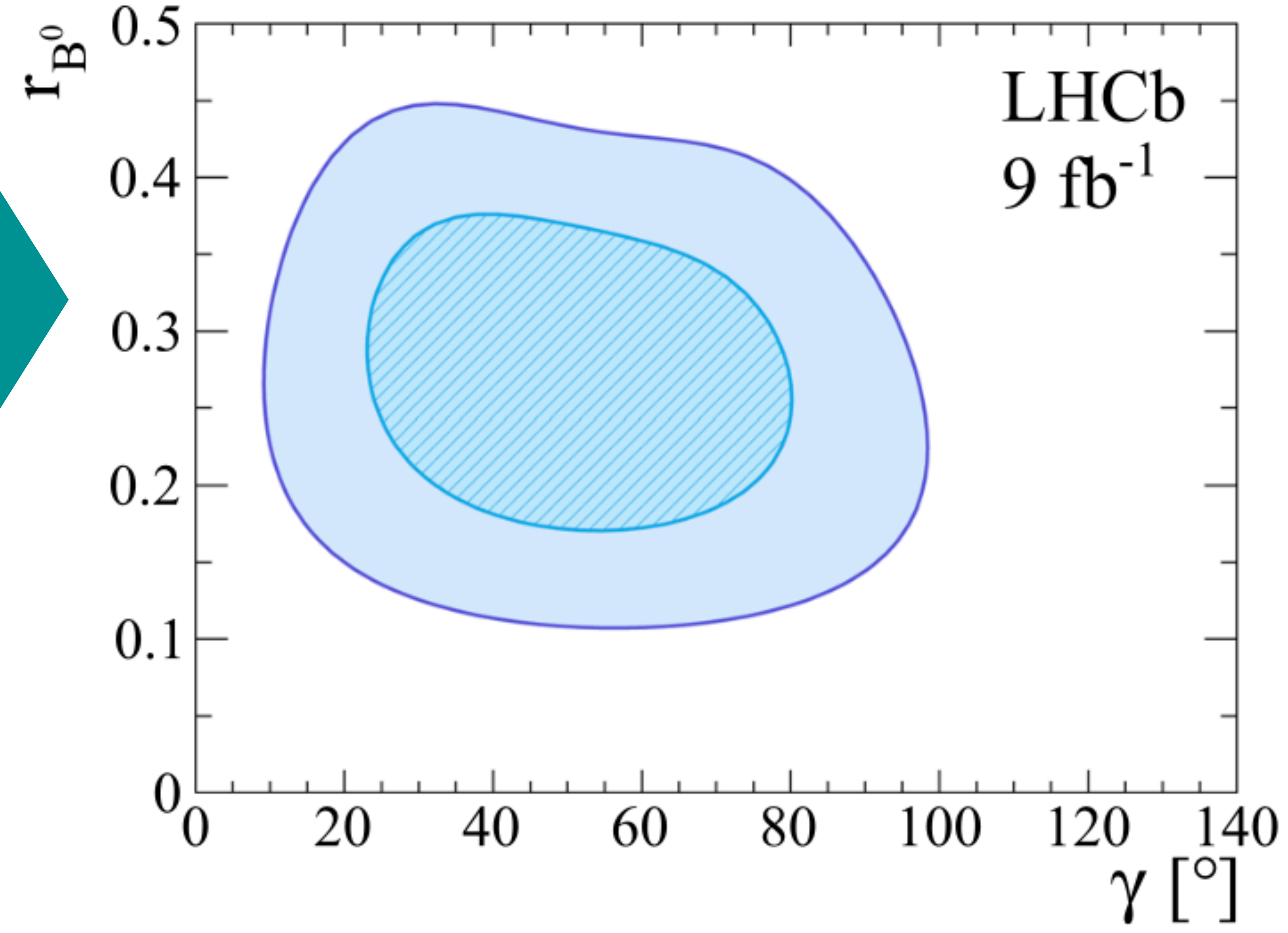
✦ The uncertainty on γ statistically dominated.

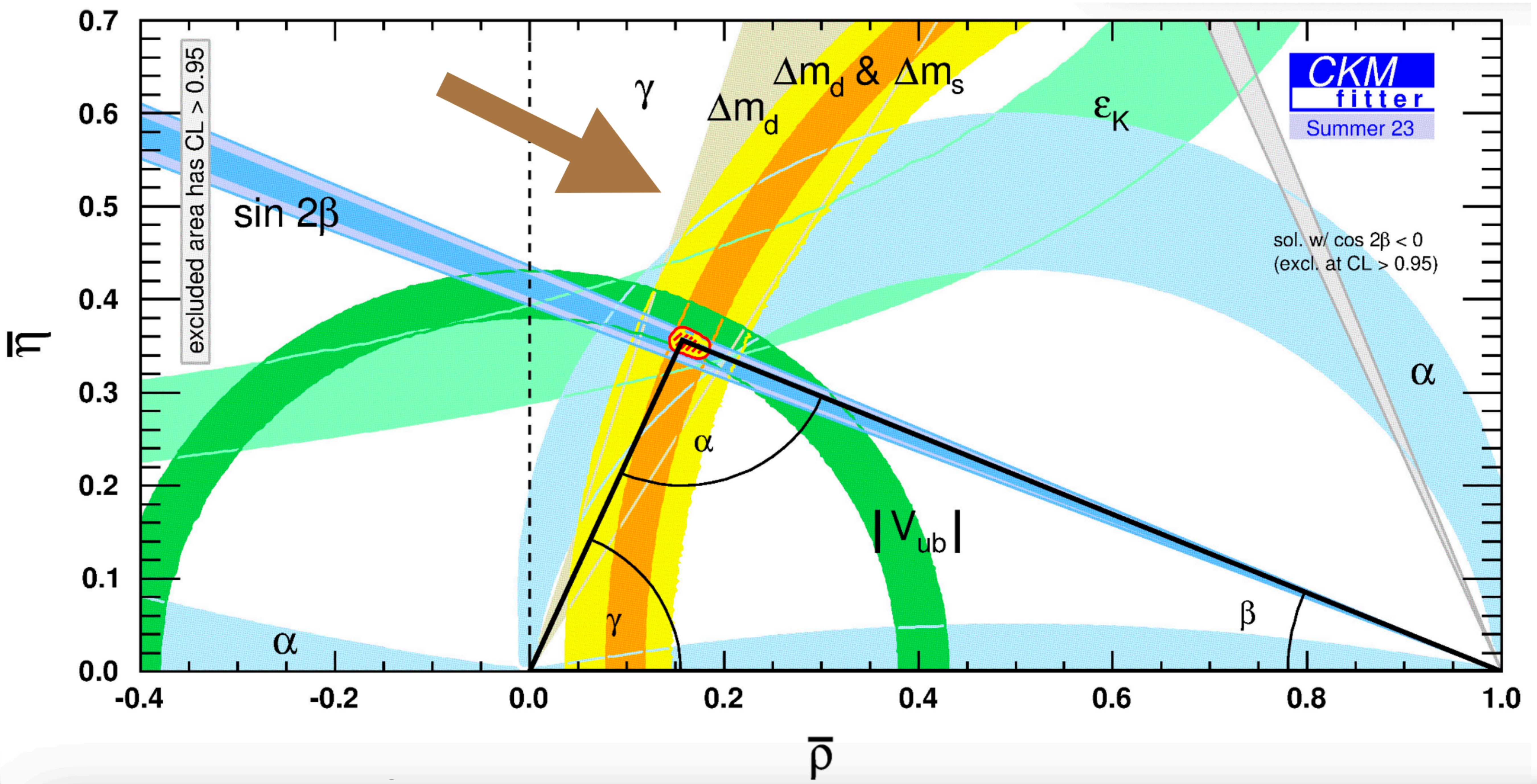
✦ Reduces tension between B^+ and B^0 results !

✦ The precision of the CP observables expected to be improved with Run3 data!

✦ Measurements supersede [J. High Energ. Phys. 2016, 131 (2016) 1]







JHEP05(2024)025

Study of CP violation in $B^0 \to DK^*(892)^0$ decays with $D \to K\pi(\pi\pi), \pi\pi(\pi\pi), KK$ final states

✓ Measurements of CP-violating observables associated with the interference of in the decays of $B^0 \to D^0 K^*(892)^0$ and $B^0 \to \bar{D}^0 K^*(892)^0$ decay amplitudes performed in the $D^0 \to K^\mp\pi^\pm(\pi^+\pi^-)$, $D^0 \to \pi^+\pi^-(\pi^+\pi^-)$ final states

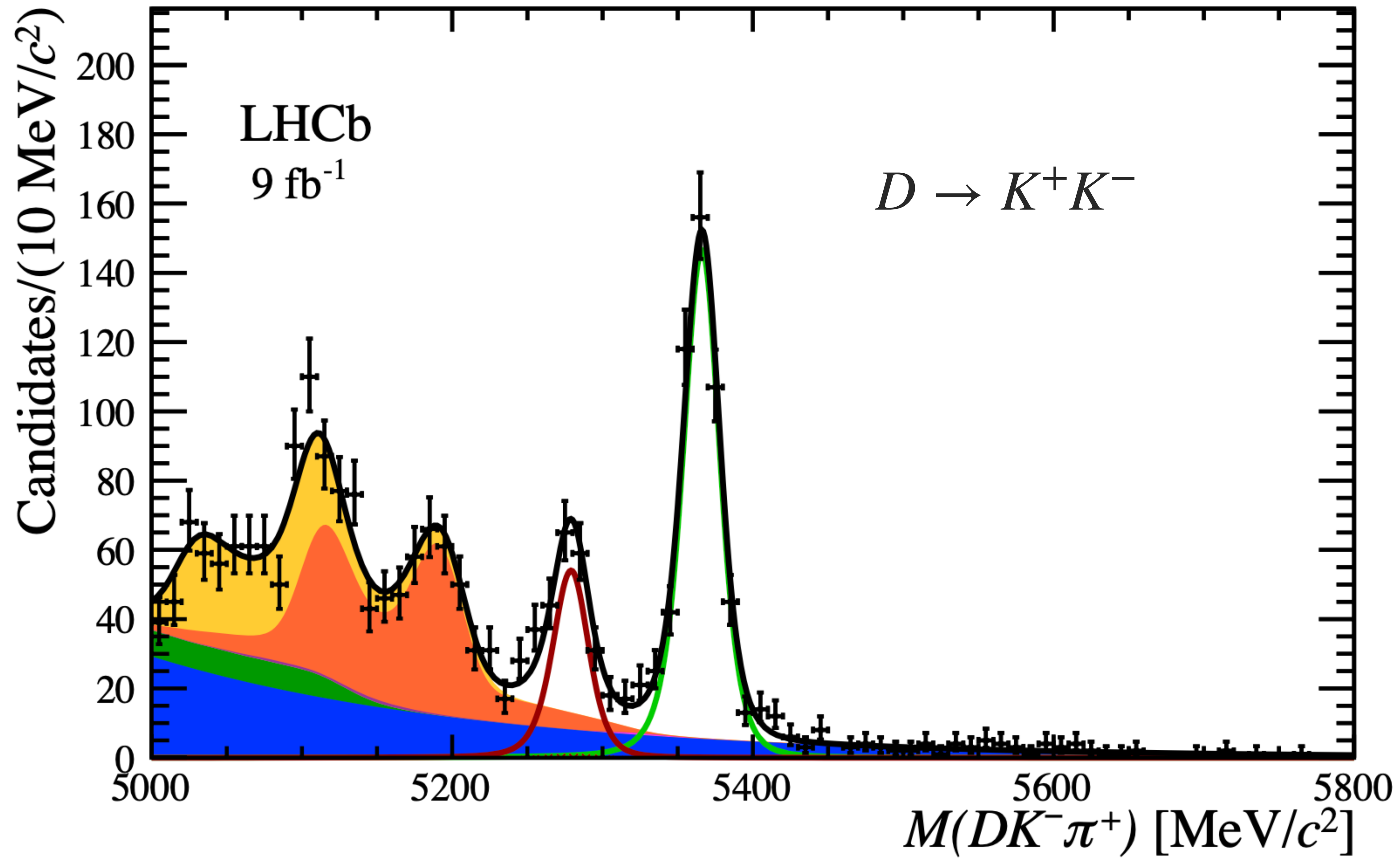
✓ The $K^*(892)^0$ meson is referred as K^{*0}, where decays to $K^+\pi^-$

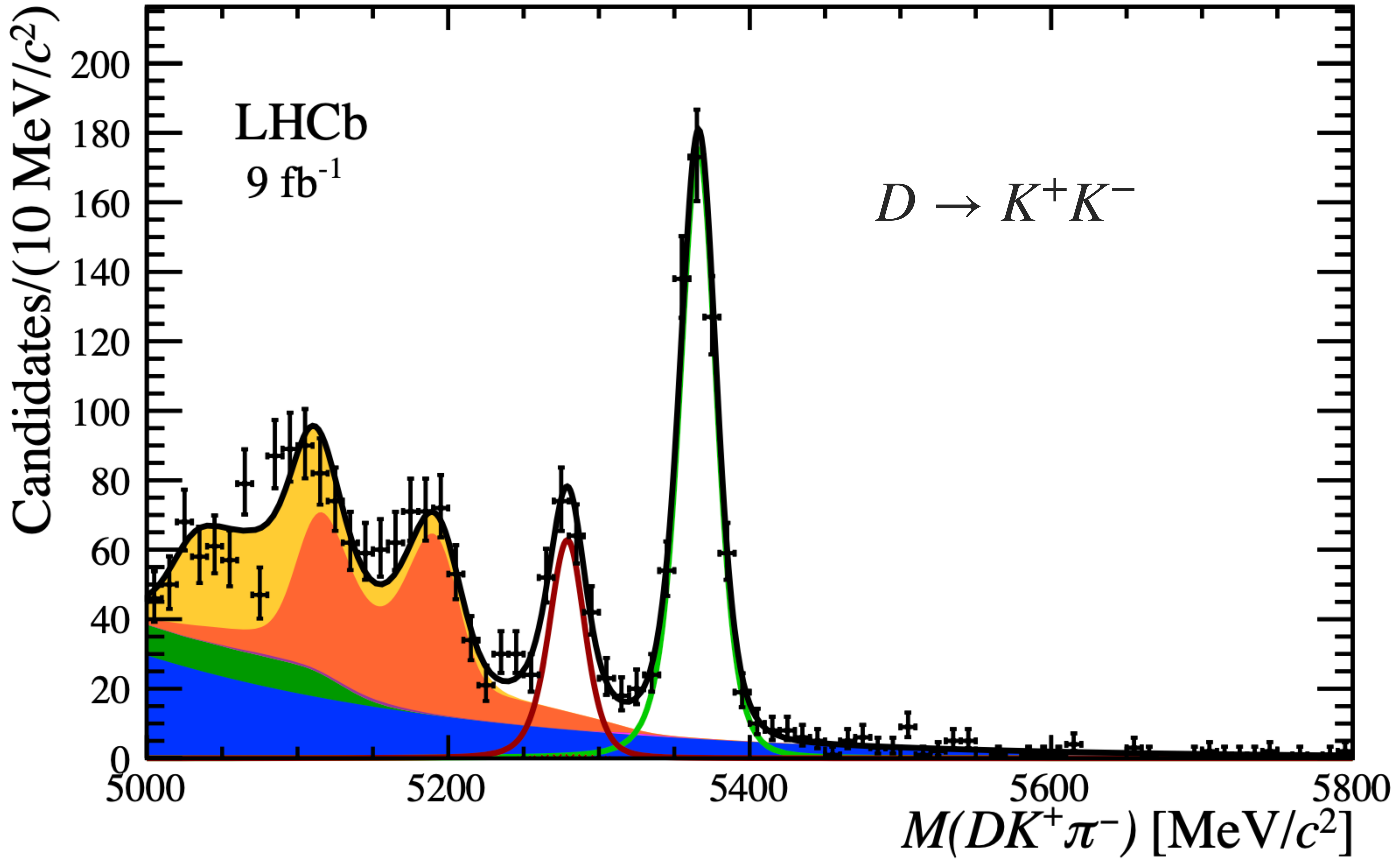
✓ ADS (CF, DCS decays like $D^0 \to K^\mp\pi^\pm(\pi^+\pi^-)$, etc.) and GLW (CP-eigenstate decays $D^0 \to \pi^+\pi^-, K^+K^-$, etc.) methods performed

✓ Analysis based on Run1+Run2 data samples corresponding to an integrated luminosity of 9fb^{-1}

Measurement of the CKM angle γ with $B^0 \to D(\to K\pi(\pi\pi), \pi\pi(\pi\pi, KK))K^*$

JHEP 2405 (2024) 025



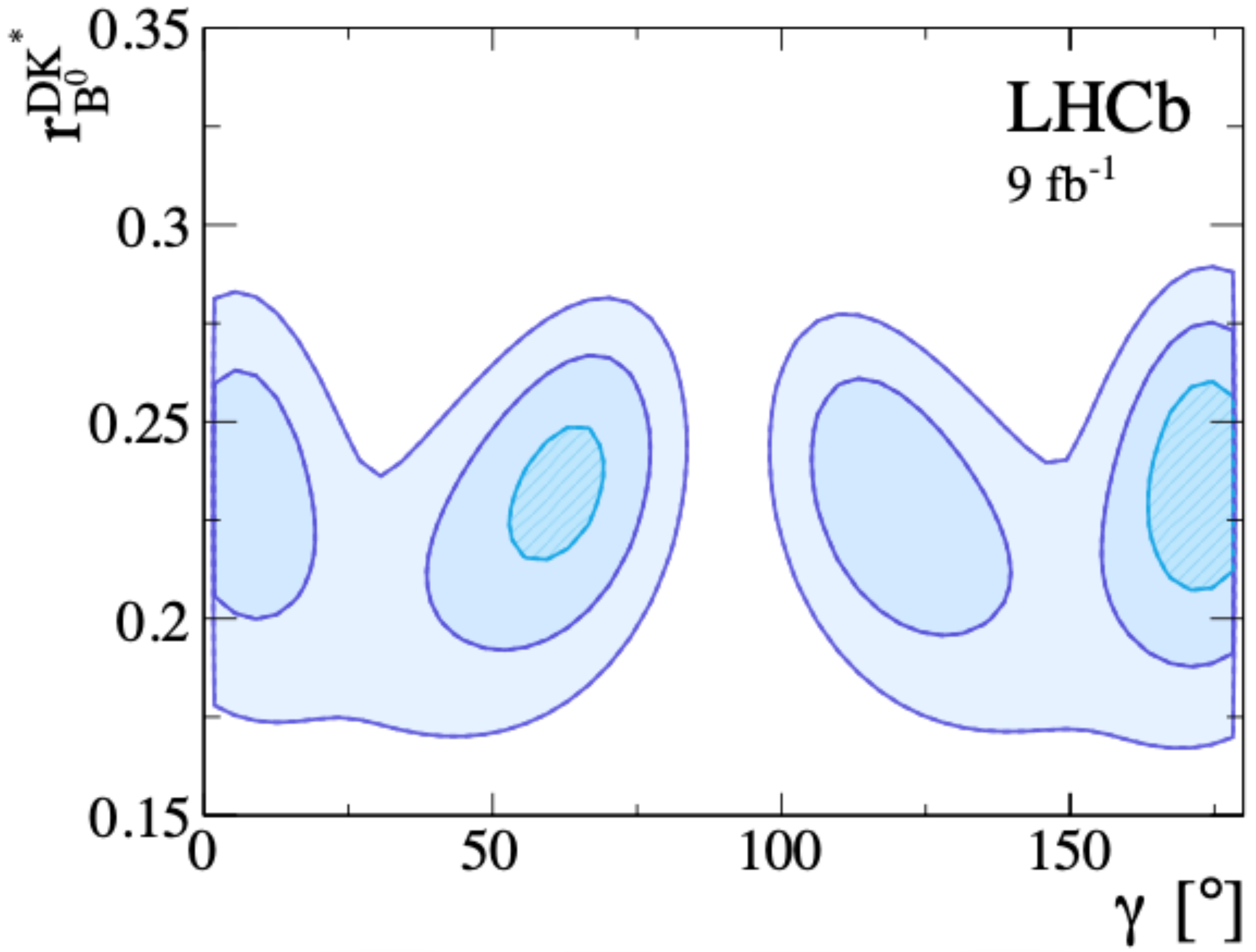


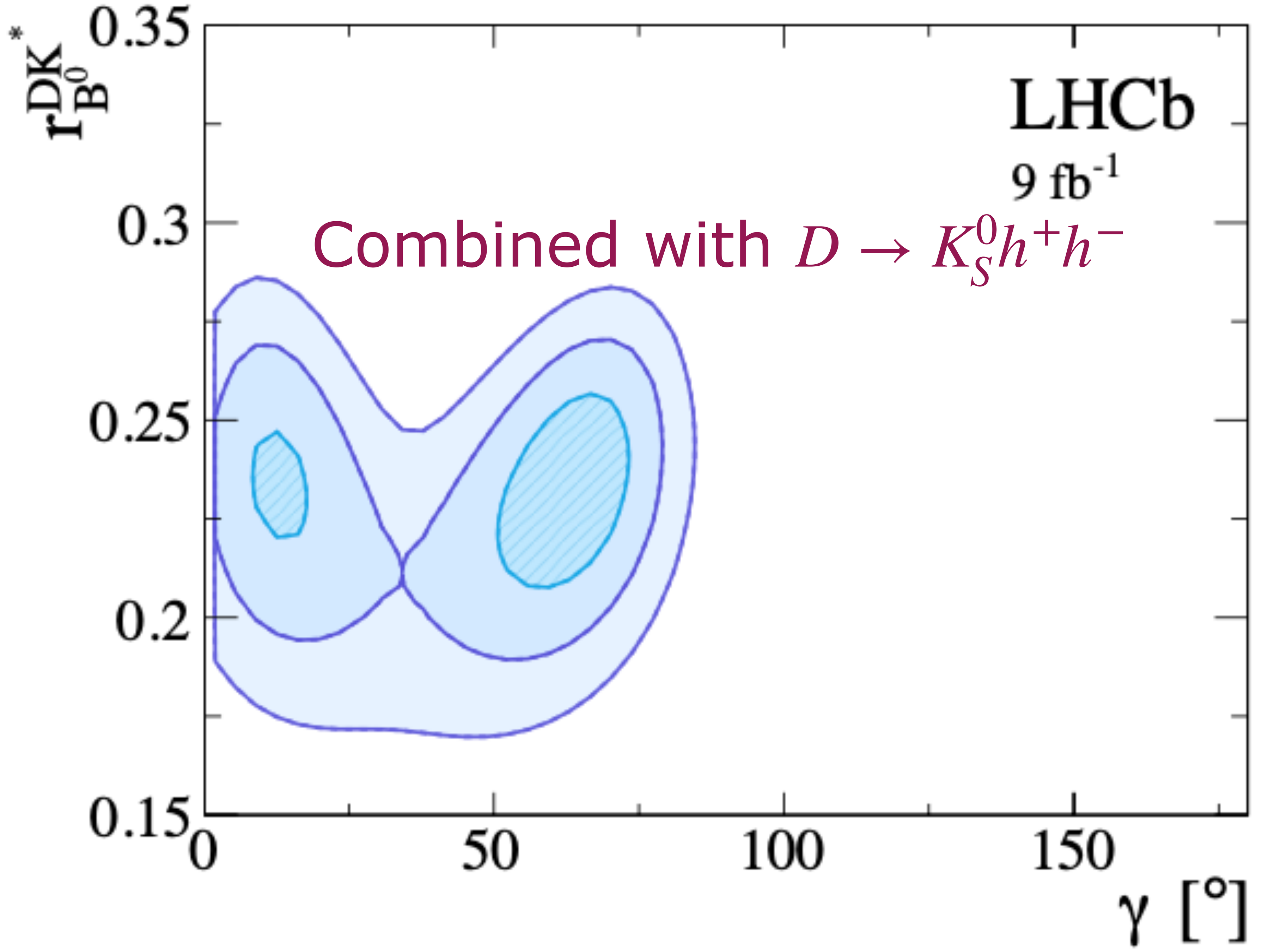
- Simultaneous unbinned extended maximum likelihood fit of the B^0 reconstructed mass for each D final state flavour
  - $D \to K^{\mp}\pi^{\pm}(\pi^+\pi^-)$
  - $D \to \pi^+\pi^-(\pi^+\pi^-)$
  - $D \to K^+K^-$
- B flavour identification from the charge of the kaon child of $K^{*0}(892) \to K^+\pi^-$ (self-tagging)
- CP-observables: ratio and asymmetry measured of ADS/GLW modes
- 60% improvement on the statistical precision of CP-observables wrt the previous results

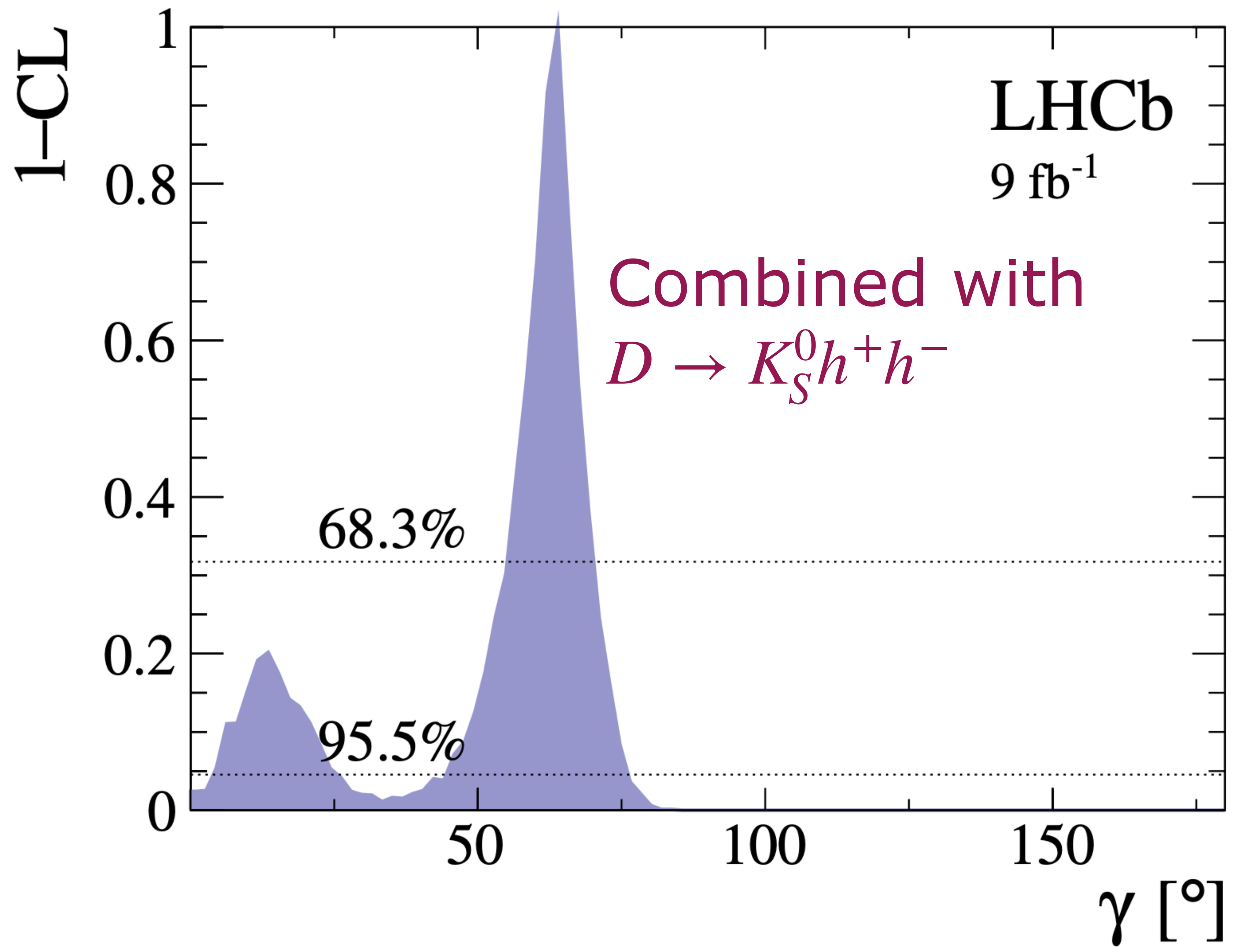
$\mathcal{R}_{CP}^{KK}$	$0.811 \pm 0.057 \pm 0.017$
$\mathcal{A}_{CP}^{KK}$	$-0.047 \pm 0.063 \pm 0.015$
$\mathcal{R}_{CP}^{\pi\pi}$	$1.104 \pm 0.111 \pm 0.026$
$\mathcal{A}_{CP}^{\pi\pi}$	$-0.034 \pm 0.094 \pm 0.016$
$\mathcal{R}_{CP}^{4\pi}$	$0.882 \pm 0.086 \pm 0.033$
$\mathcal{A}_{CP}^{4\pi}$	$0.021 \pm 0.087 \pm 0.016$

Measurement of the CKM angle γ with $B^0 \to D(\to K\pi(\pi\pi), \pi\pi(\pi\pi, KK))K^*$

JHEP 2405 (2024) 025







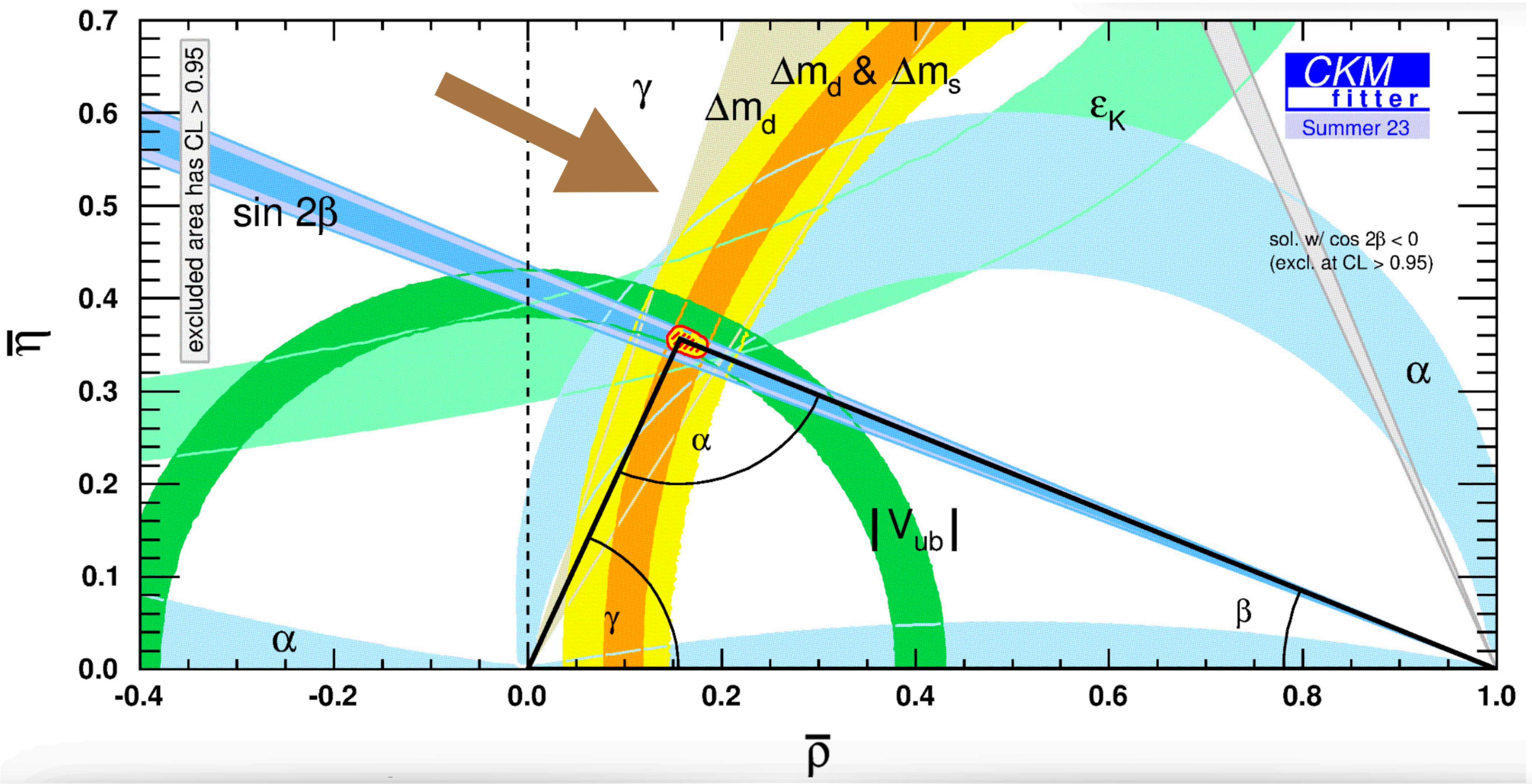
$\gamma = (61.7 \pm 8.0)^\circ$

- The most compatible γ obtained from multiple of solutions
- Combined results of physics parameters with $D \to K_S^0 h^+ h^-$
- Coherence with the LHCb γ combination!
- Most precise result in $B^0 \to DK^*(892)^0$ decays to date
- **Combination shows competitive sensitivity on γ with the B^+ decays**

$\gamma = (63.2^{+6.9}_{-8.1})^\circ$

$r_B^{D^*K} = 0.233 \pm 0.016$

$\delta_B^{D^*K} = (192.1^{+6.7}_{-6.1})^\circ$



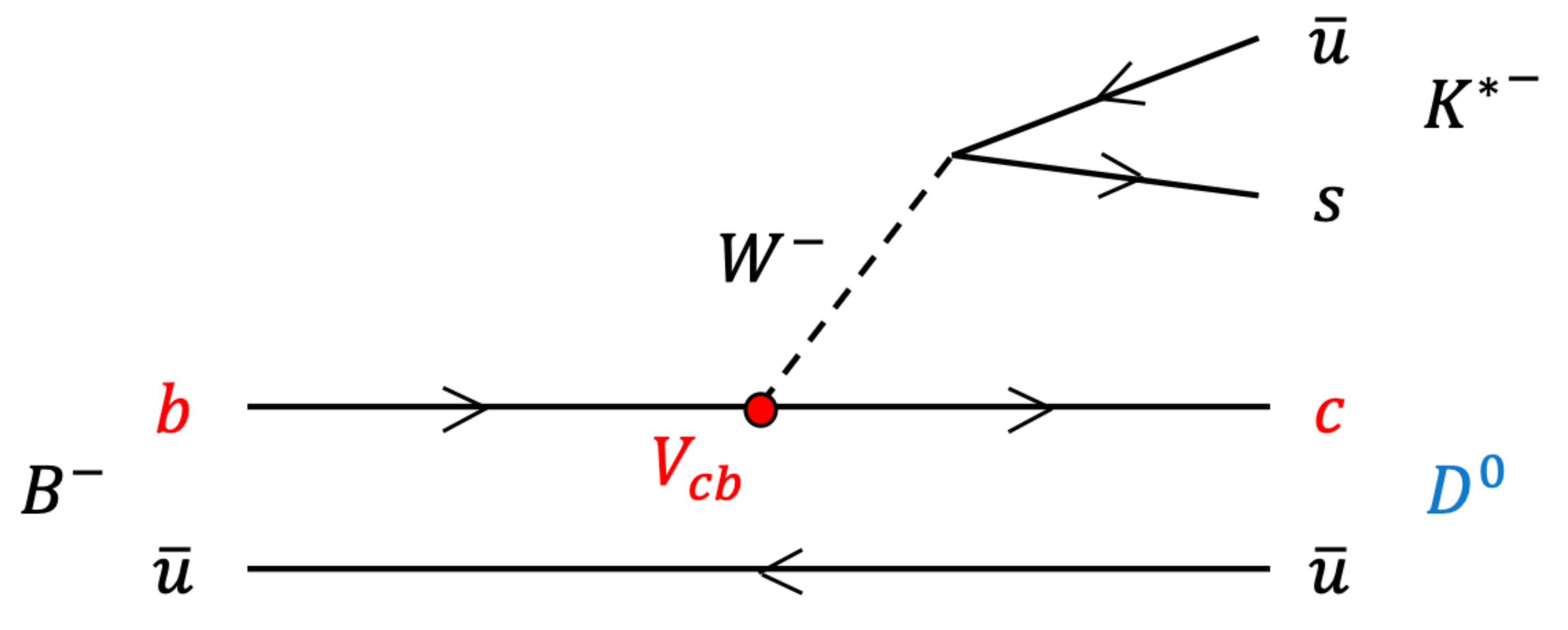
(Preliminary)

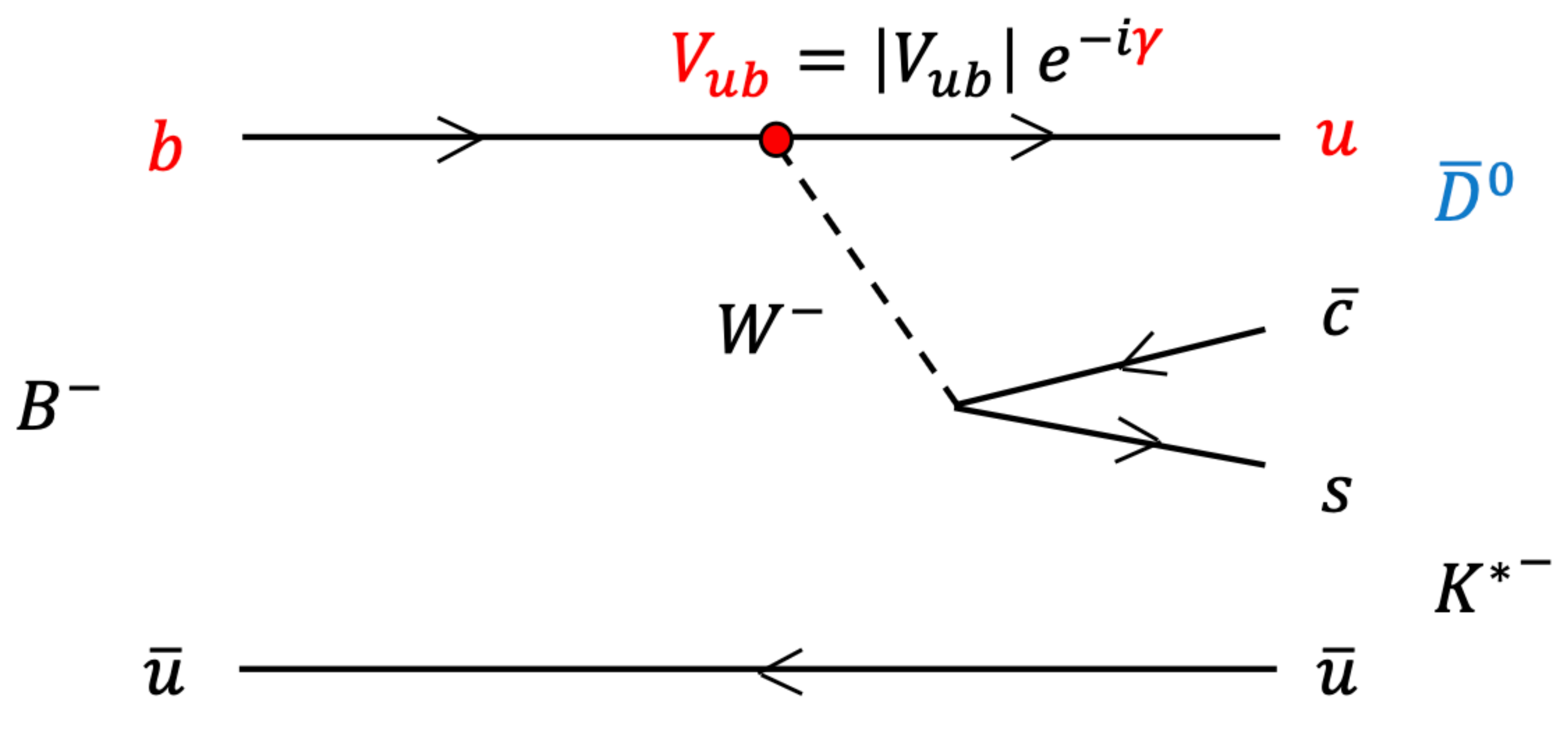
LHCb-PAPER-2024-023

Measurement of the CKM angle γ in $B^\pm \to DK^{*\pm}$ decays

✓ Measurements are performed from CP observables and the CKM angle γ in $B^\pm \to DK^{*\pm}$ where $K^{*\pm}$ refers to the $K^*(892)^\pm$ resonance, decays to $K^{*\pm} \to K_s^0\pi^\pm$ and D represents a superposition of D^0 and $\bar{D}^0$ states.

✓ Analysis based on Run1+Run2 data samples corresponding to an integrated luminosity of 9fb^{-1}

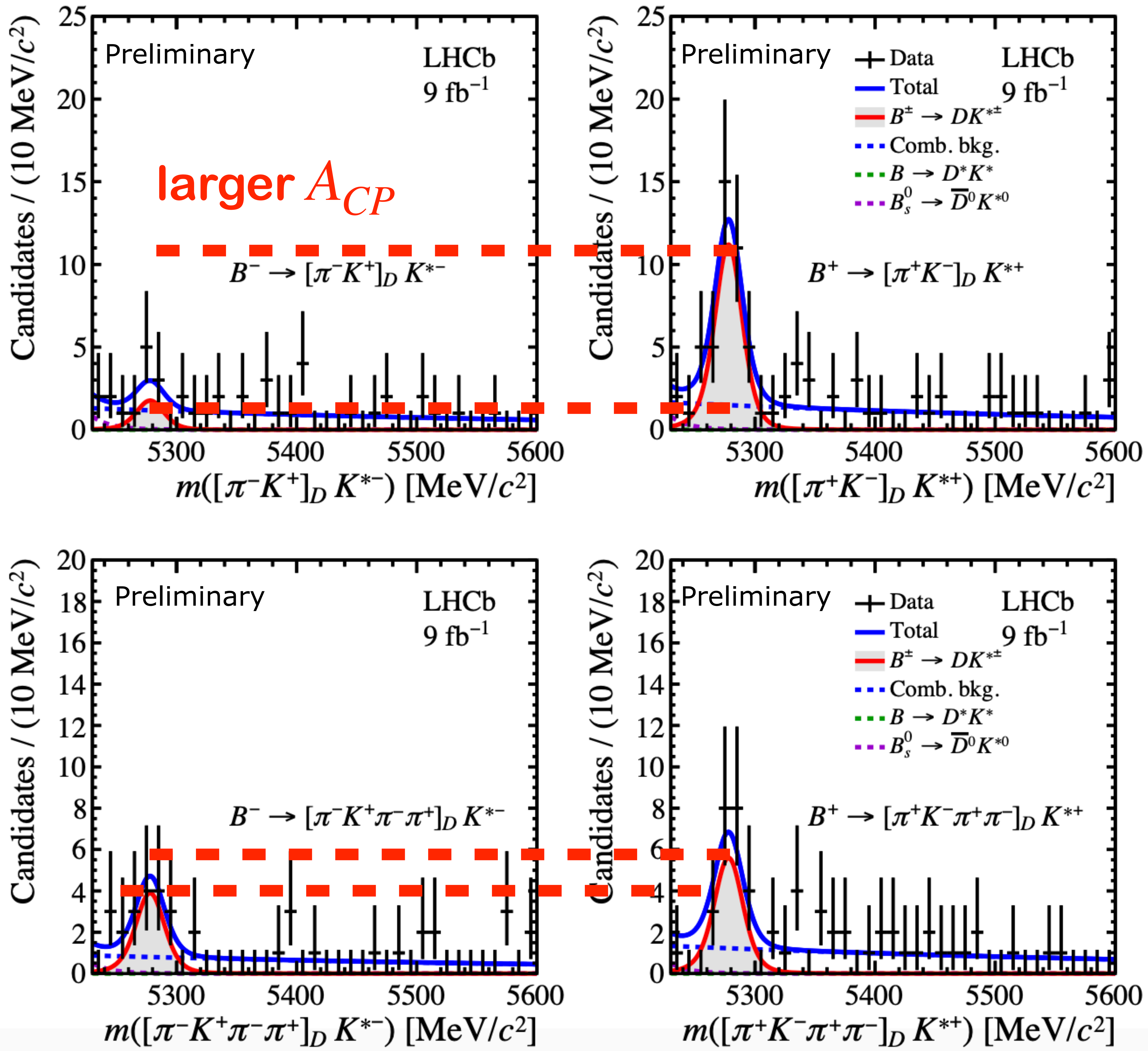




Measurement of the CKM angle γ in $B^{\pm} \to DK^{*\pm}$

(Preliminary) **NEW**

LHCb-PAPER-2024-023



- $B^{\pm} \to DK^{*\pm}$ has similar BF and provide similar sensitivity to γ as $B^{\pm} \to DK^{\pm}$ golden channel
- combined results of ADS/GLW and BPGGSZ to determine the CP observables:
  - $D \to \pi^{\pm} K^{\mp} (\pi^{\pm} \pi^{\mp})$
  - $D \to \pi^+ \pi^- (\pi^+ \pi^-)$
  - $D \to K^+ K^-$
  - $D \to K_S^0 h^+ h^-$, where $h \to K, \pi$
- First time measurement for $B^{\pm} \to DK^{*\pm}$, where $D \to K_S^0 h^+ h^-$ at LHCb
- The lower yields from $B^{\pm} \to DK^{*\pm}$ than $B^{\pm} \to DK^{\pm}$, difference of the reconstruction efficiency of $K^{*\pm}$ and $K^{\pm}$
  - extremely lower background!
- First observation of the suppressed $B^{\pm} \to [\pi^+ K^-]_D K^{*\pm}$ and $B^{\pm} \to [\pi^+ K^- \pi^+ \pi^-]_D K^{*\pm}$ decays

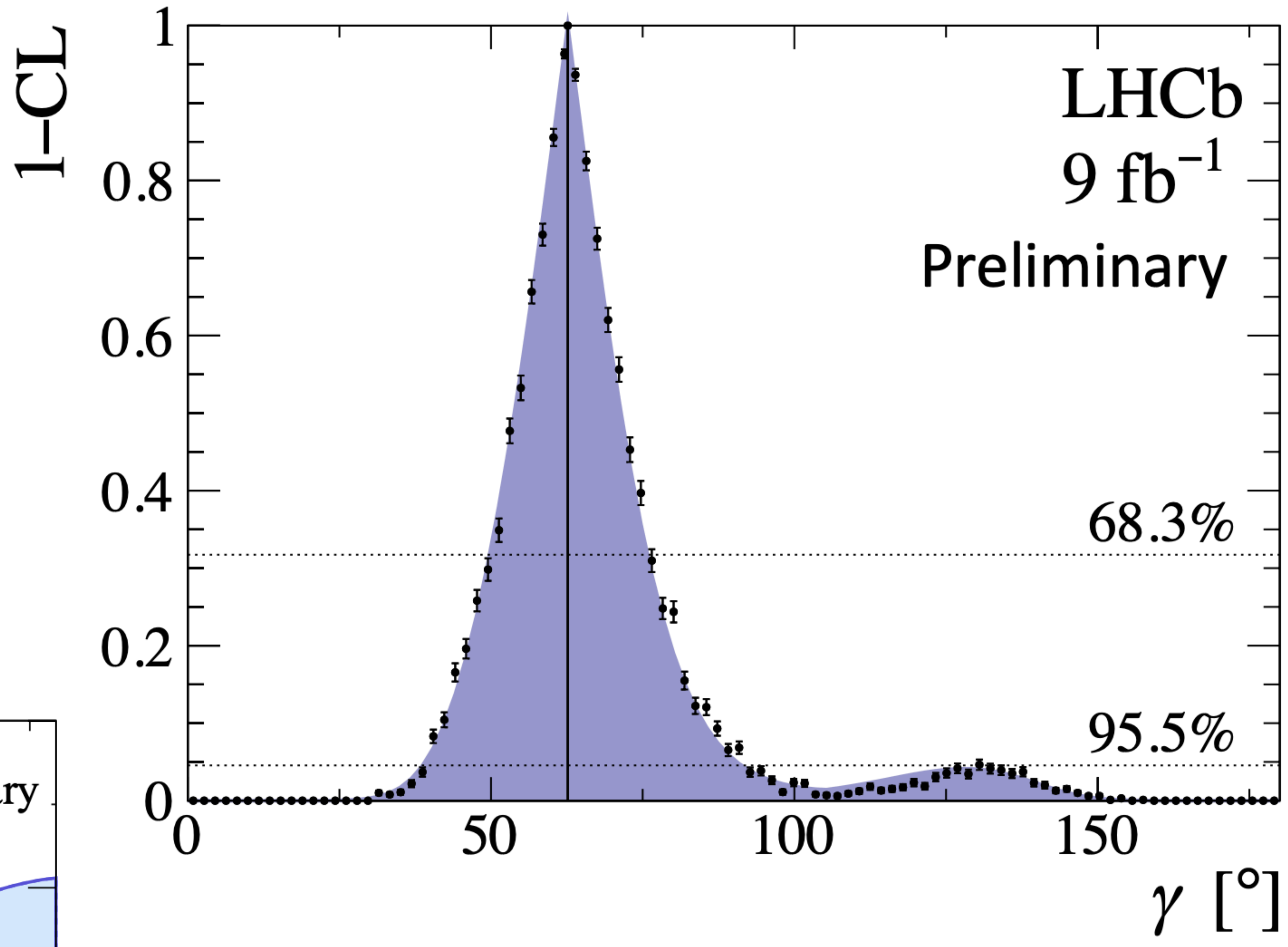
$A_{\pi K} = -0.73 \pm 0.16 \pm 0.03$ $\quad$ $A_{\pi K \pi \pi} = -0.19 \pm 0.22 \pm 0.01$

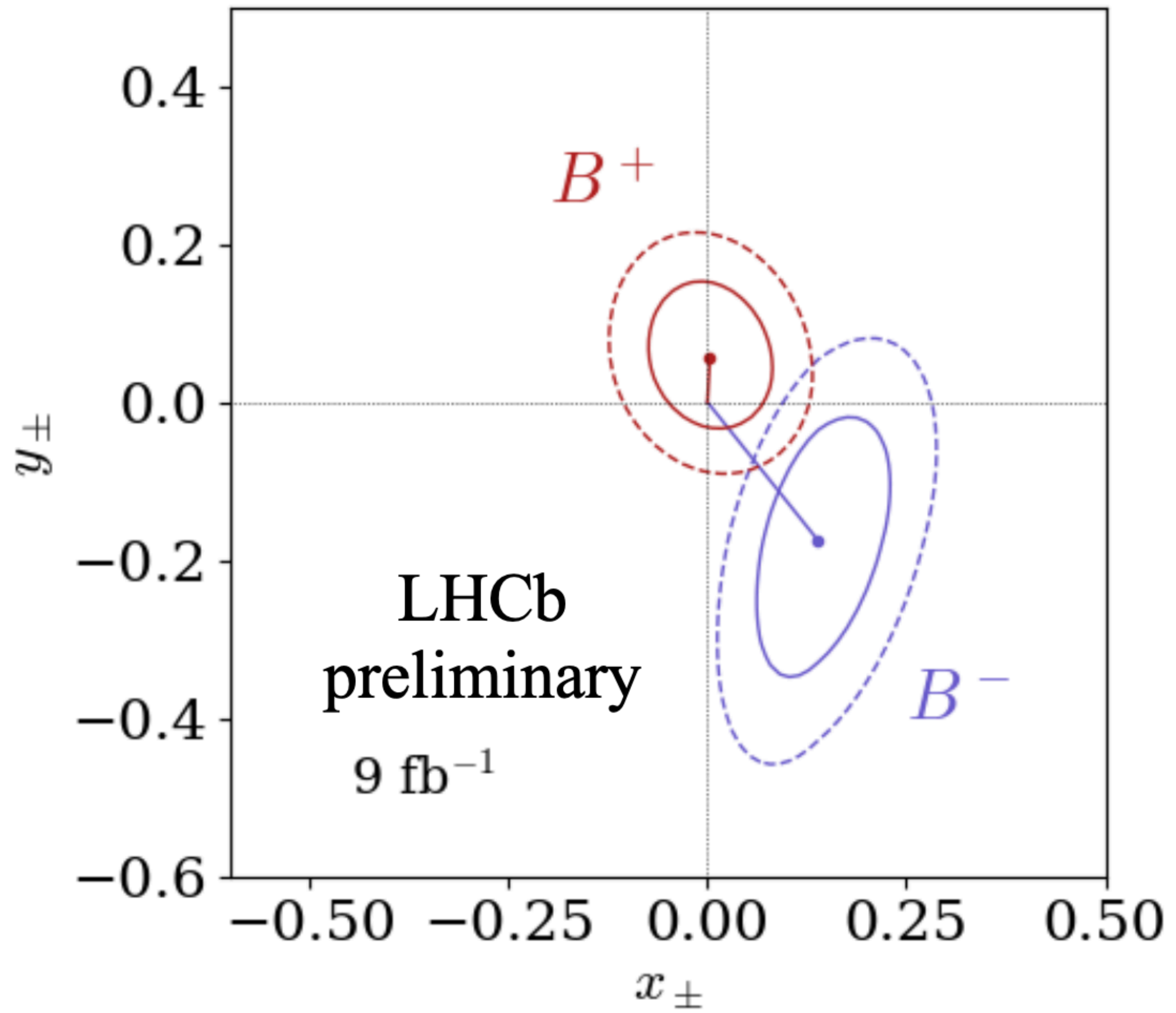
Measurement of the CKM angle γ in $B^{\pm} \to DK^{*\pm}$

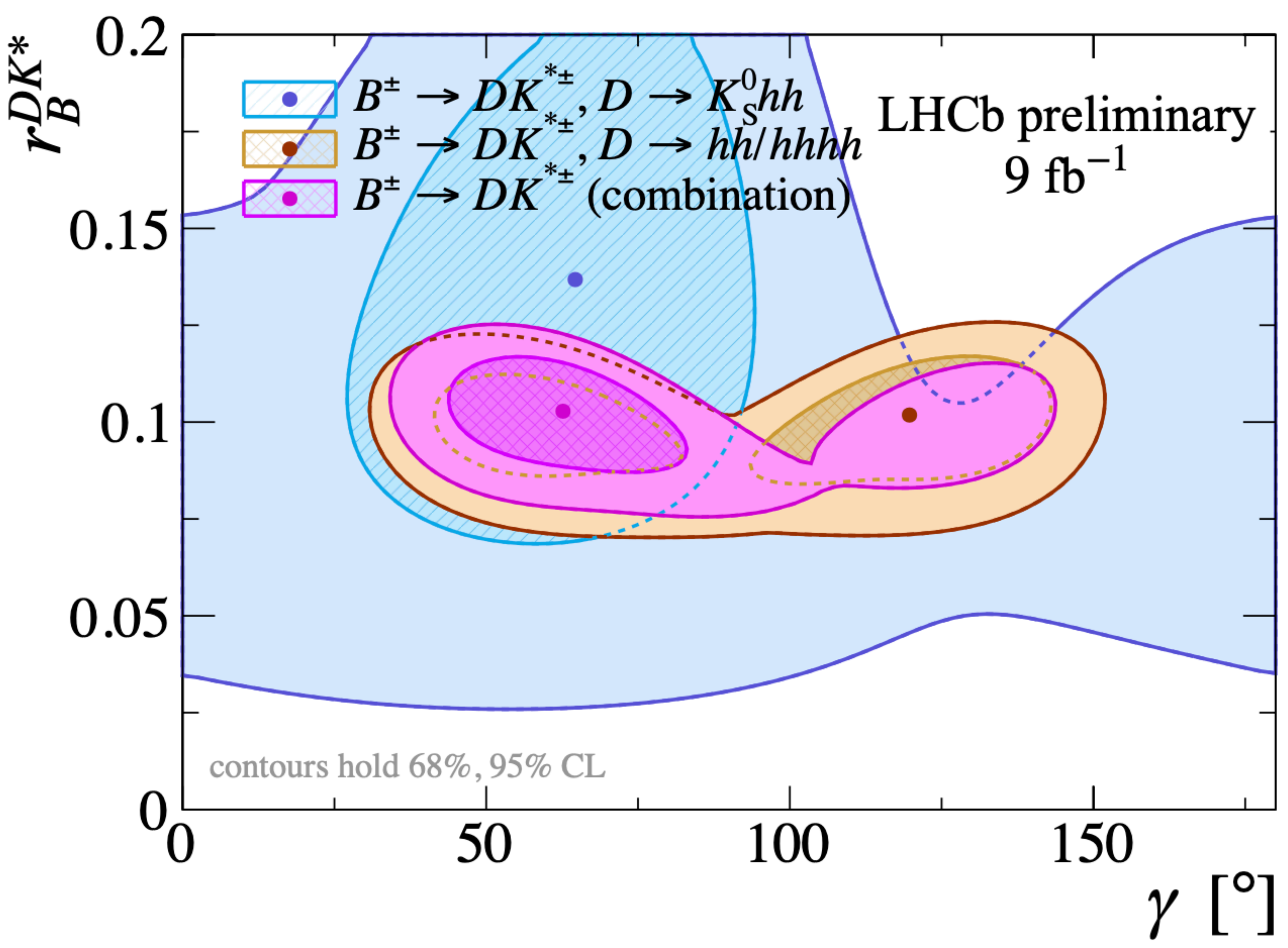
(Preliminary) NEW

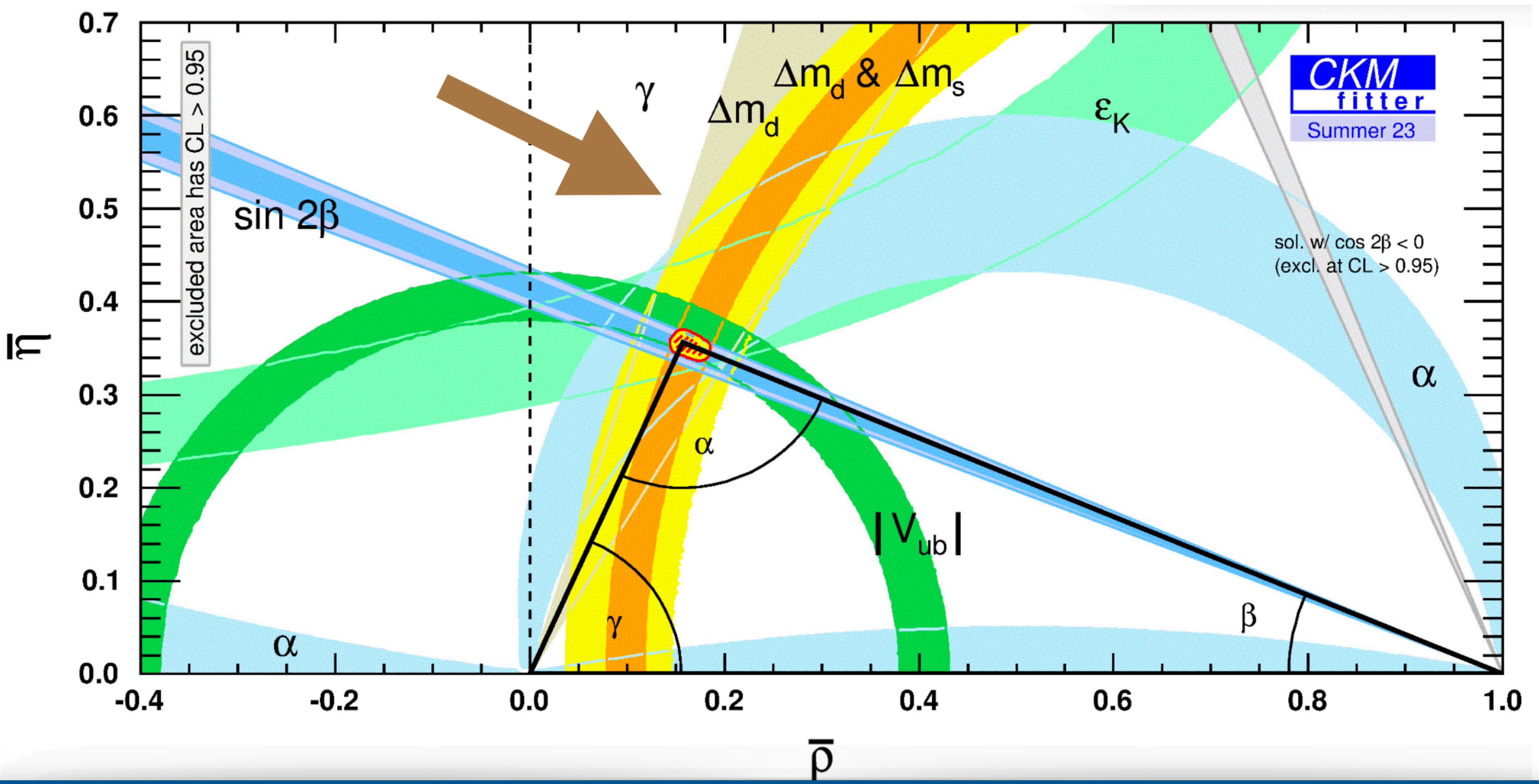
LHCb-PAPER-2024-023

- External inputs measured by CLEO and BESIII Collaborations
- **Result can be interpreted in term of** $\gamma = (63 \pm 13)°$
- **Consistent with the world average !** [Phys. Rev. D 107, 052008]









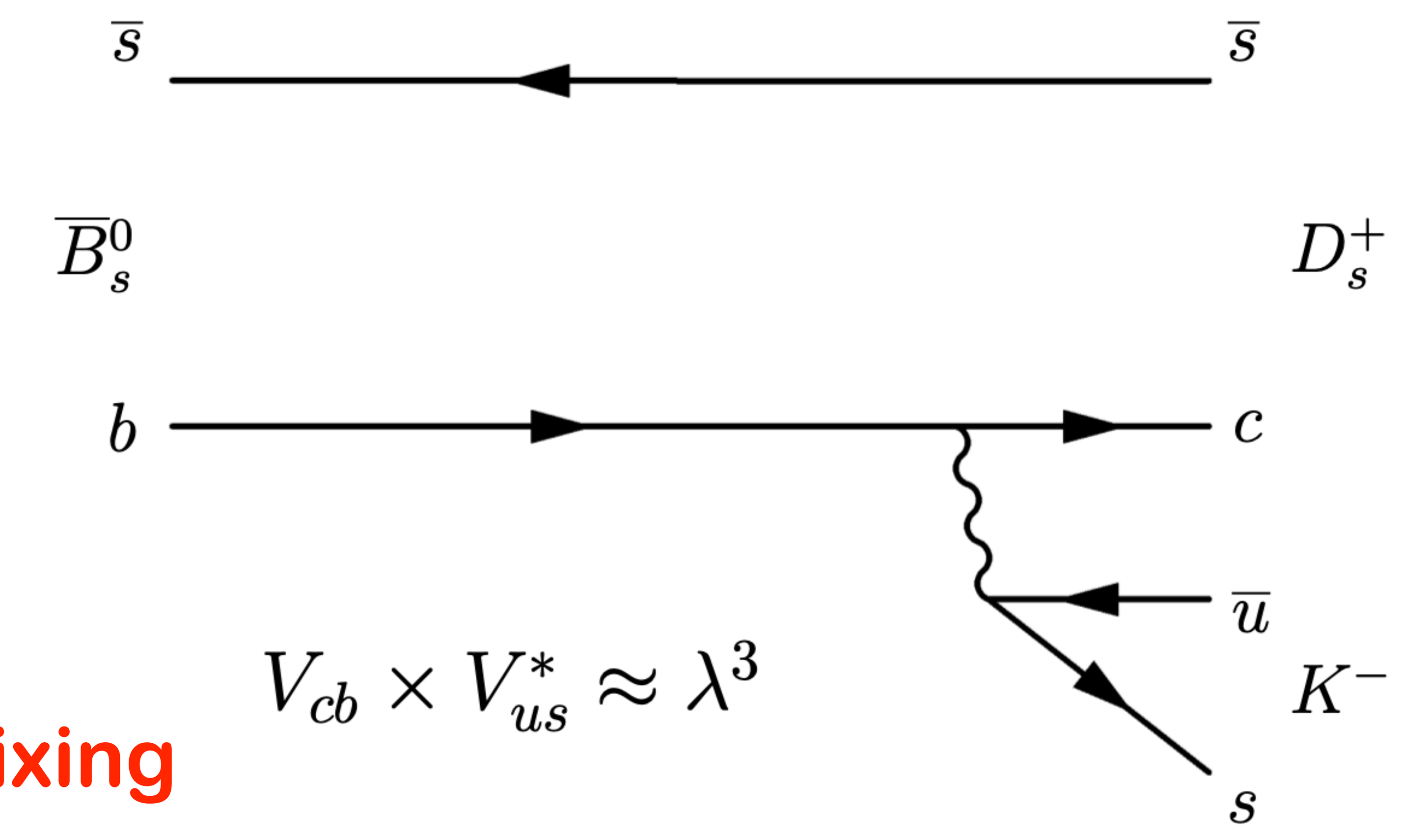
(Preliminary)

LHCb-PAPER-2024-020

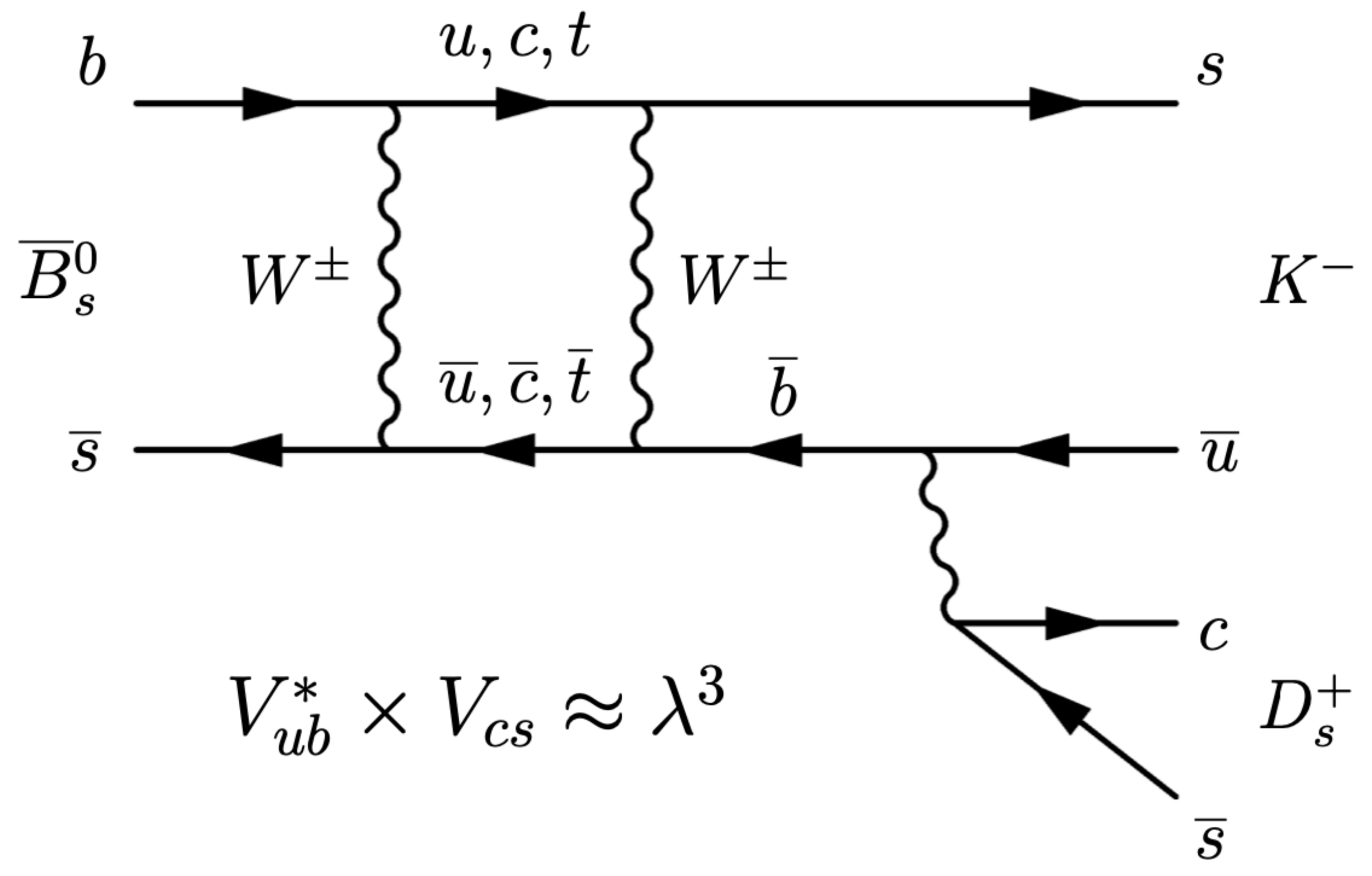
Measurement of CP asymmetry in $B_s^0 \to D_s^{\mp} K^{\pm}$ decays

✓ Measurement is performed of CP observables in $B_s^0 \to D_s^{\mp} K^{\pm}$

✓ Analysis based on Run2 data samples corresponding to an integrated luminosity of $6fb^{-1}$



without mixing



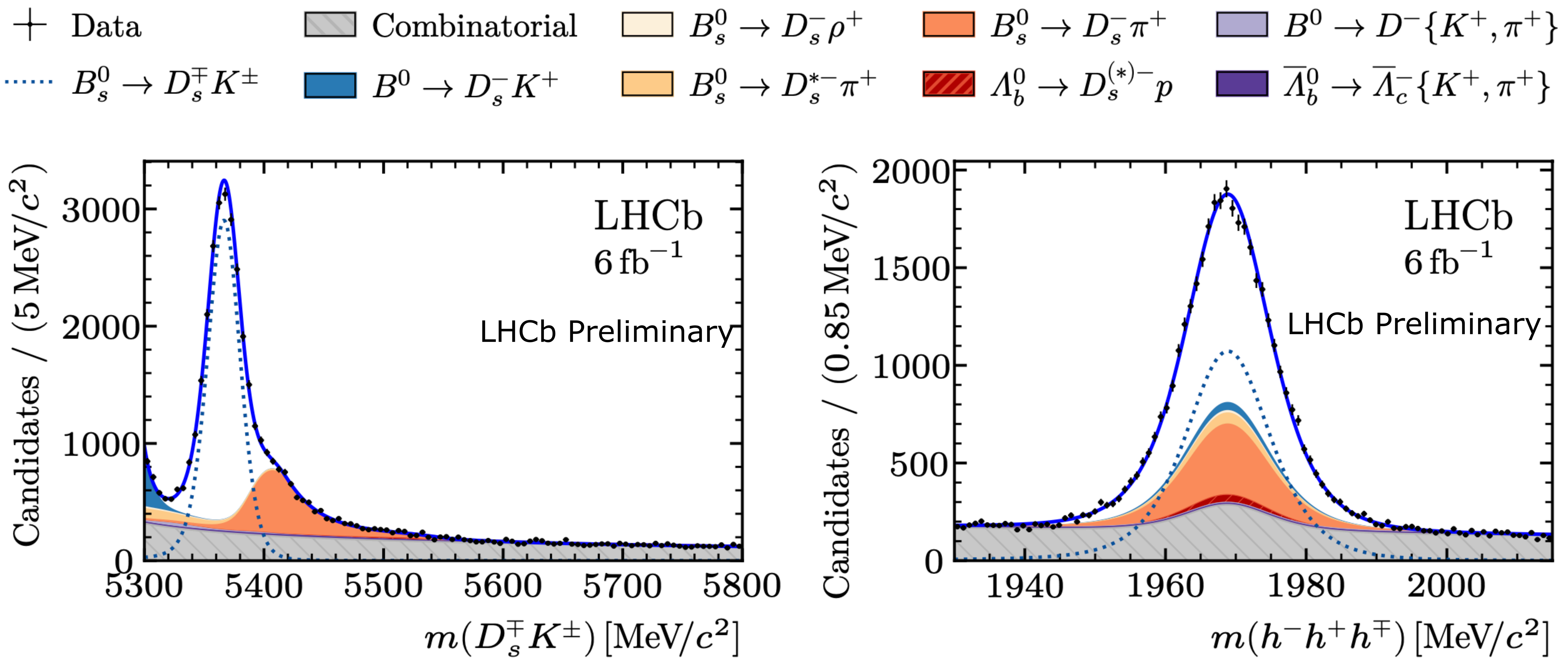
with mixing

Measurement of CP asymmetry in $B_s^0 \to D_s^- K^+$ decays

(Preliminary) NEW

LHCb-PAPER-2024-020

- Time-dependent analysis of γ :
- Simultaneous fit from all reconstructed D_s^-
  - $D_s^- \to K^+\pi^+\pi^-$
  - $D_s^- \to K^-K^+\pi^-$
  - $D_s^- \to \pi^+\pi^-\pi^-$
- CP-Observables determined in two-stage fit procedure: **(1)**
  - ✓ sPlot technique to substract backround from signal statistically
  - ✓ 2DFit performed m($D_s^{\pm}K^{\mp}$) and m($h^+h^-h^{\pm}$)
- CP-violation parameters depends on the γ and mixing phase $\beta_{(s)}$: $\gamma + 2\beta$
- Control channels : $B_s^0 \to D_s^-\pi^+$ and $B^0 \to D^-\pi^+$ decays selected

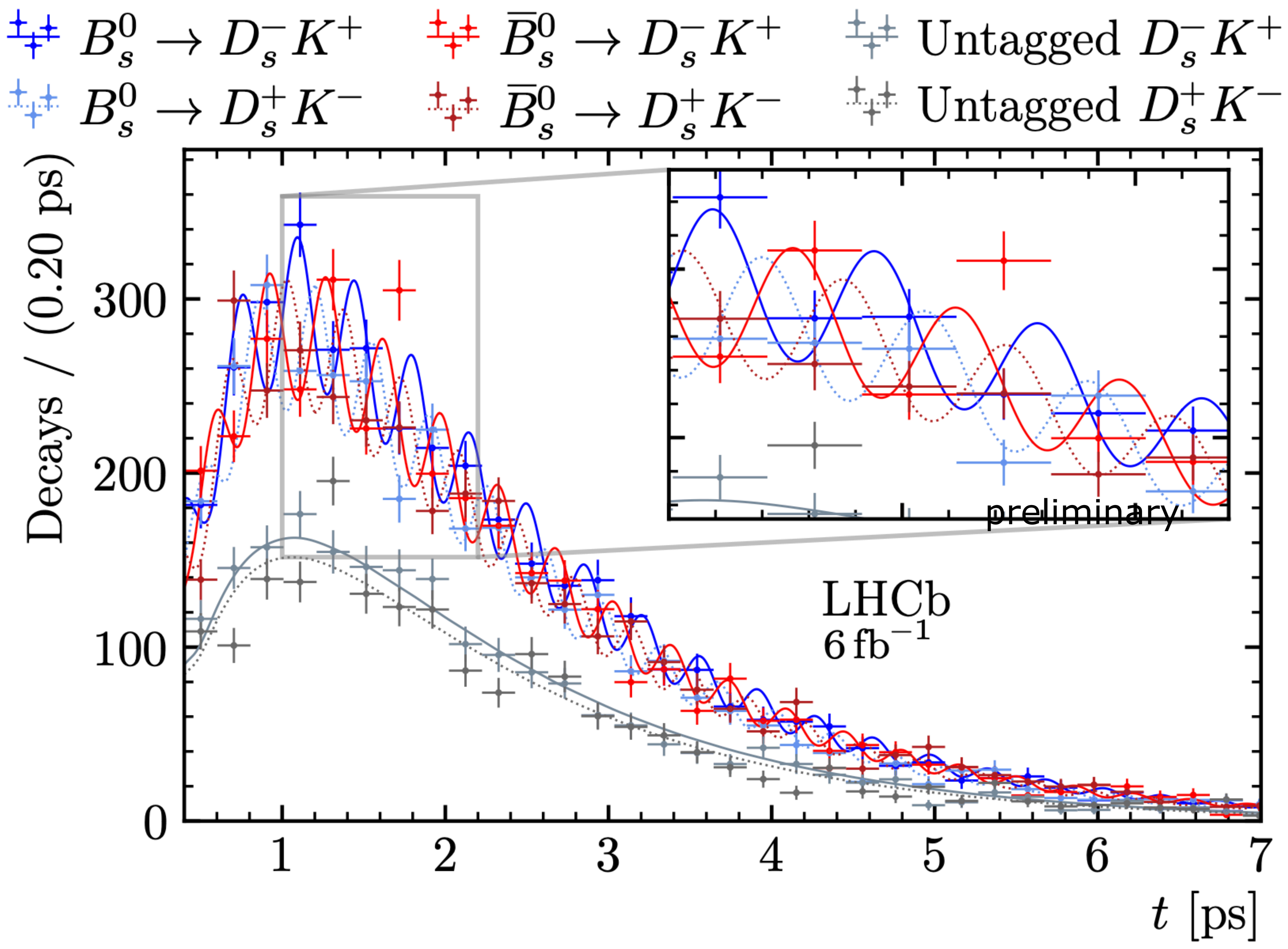


- **The yields determined to be : 20949±180**
- (uncertainties statistical only)

Measurement of CP asymmetry in $B_s^0 \to D_s^- K^+$ decays

(Preliminary) **NEW**

LHCb-PAPER-2024-020

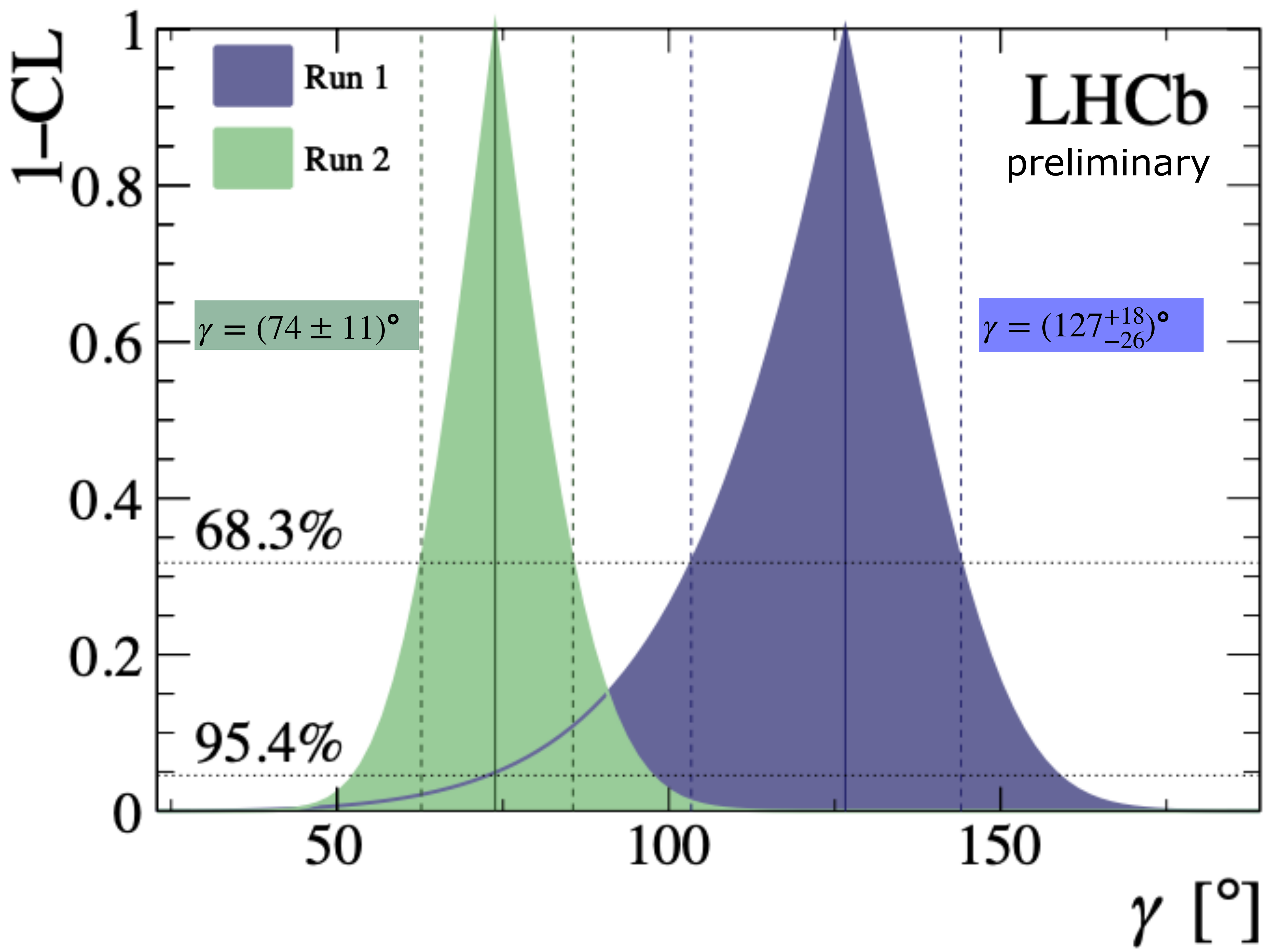


- Decay-time distribution of $B_s^0 \to D_s^{\mp} K^{\pm}$ candidates for each final states and flavour tagging.
- Requirement of the flavour-tagging algorithm: to determine initial B_s^0 flavour
- External input from LHCb $\phi_s = -0.031 \pm 0.018$ rad [arXiv:2308.01468]
- **Measured CP observables of combination between Run1+Run2 :**

$$\gamma = (81^{+12}_{-11})^\circ$$

$$r_{D_sK} = 0.318^{+0.034}_{-0.033}$$

$$\delta = (347.6 \pm 6.3)$$



- CPV observed in the interference between $B_s^0 - \bar{B}_s^0$ and $B_s^0 \to D_s^{\mp} K^{\pm}$ with a 8.6 σ
- **The most precise determination of γ in B_s^0 decays**
- Good agreement with the recent LHCb combination

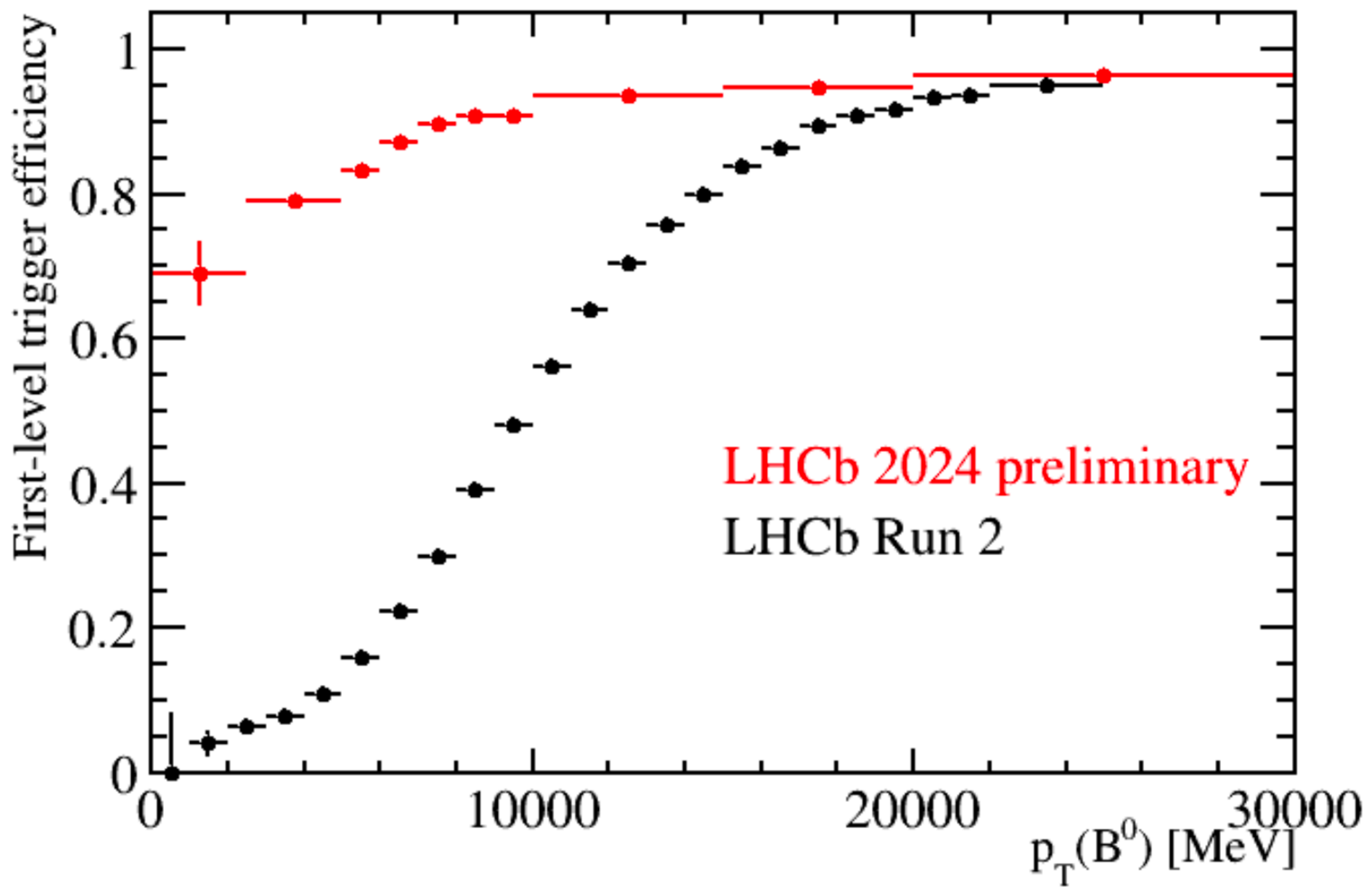
Conclusions

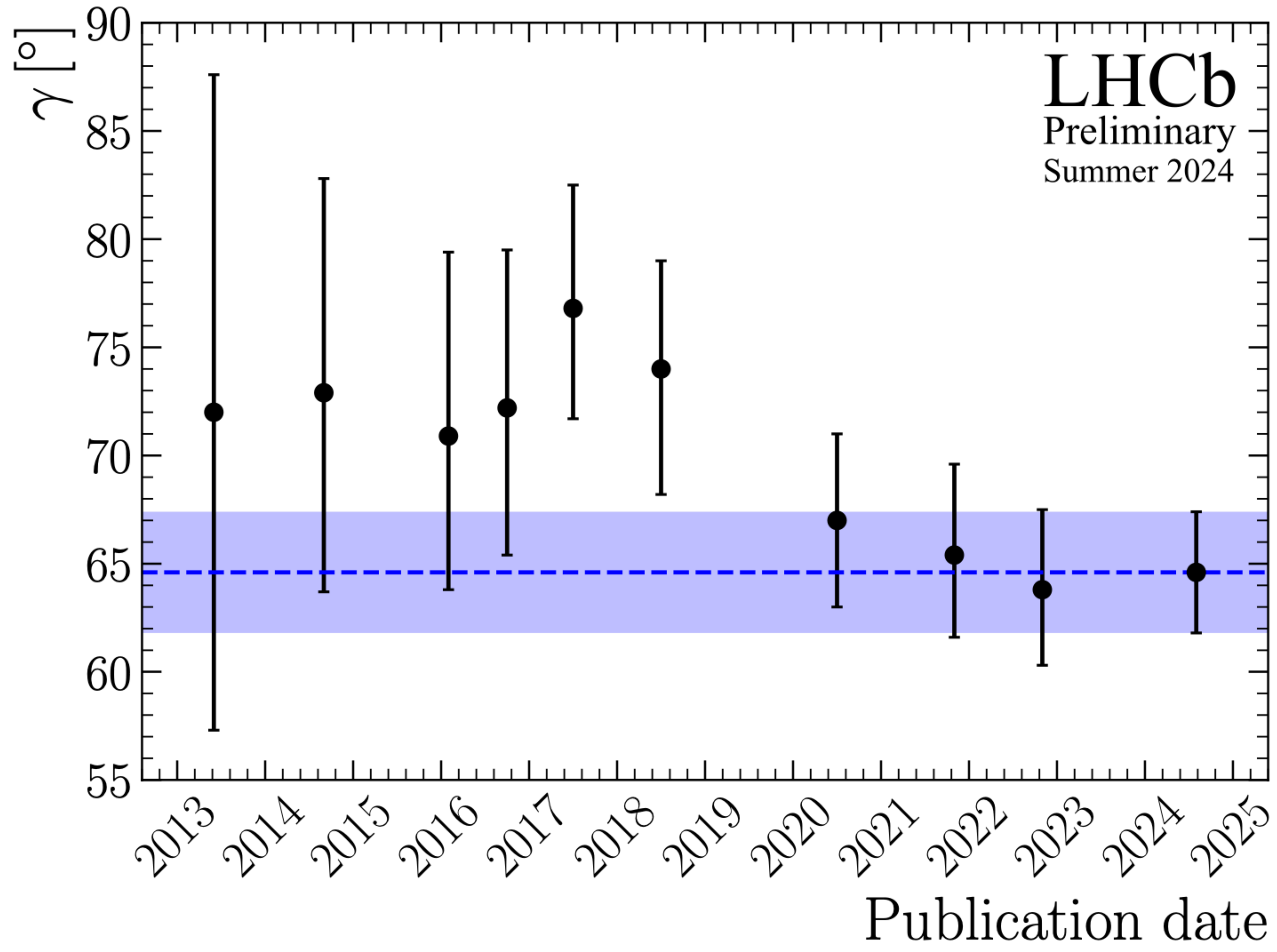
☑ Recent LHCb highlights from the seven analysis for the measurement of the CKM angle γ were presented

☑ Many analysis with Run1 + Run2 completed

☑ Run3 is in progress with the stably working detector

☑ The new software-based trigger is much more efficient on hadronic decays





☑ With the larger statistics precision on the CKM angle γ measurements and will help improving the knowledge for the future studies!

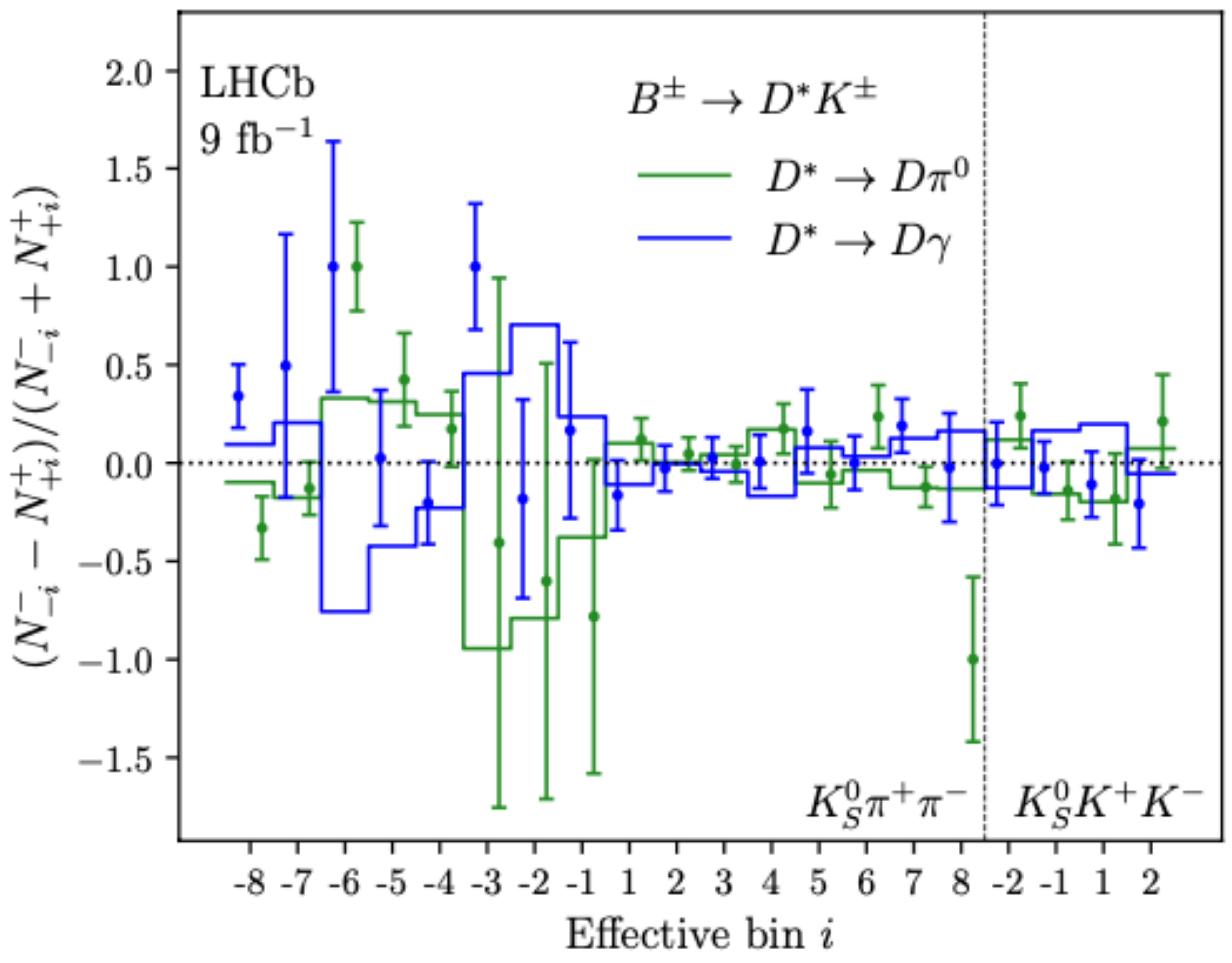
Stay Tuned!

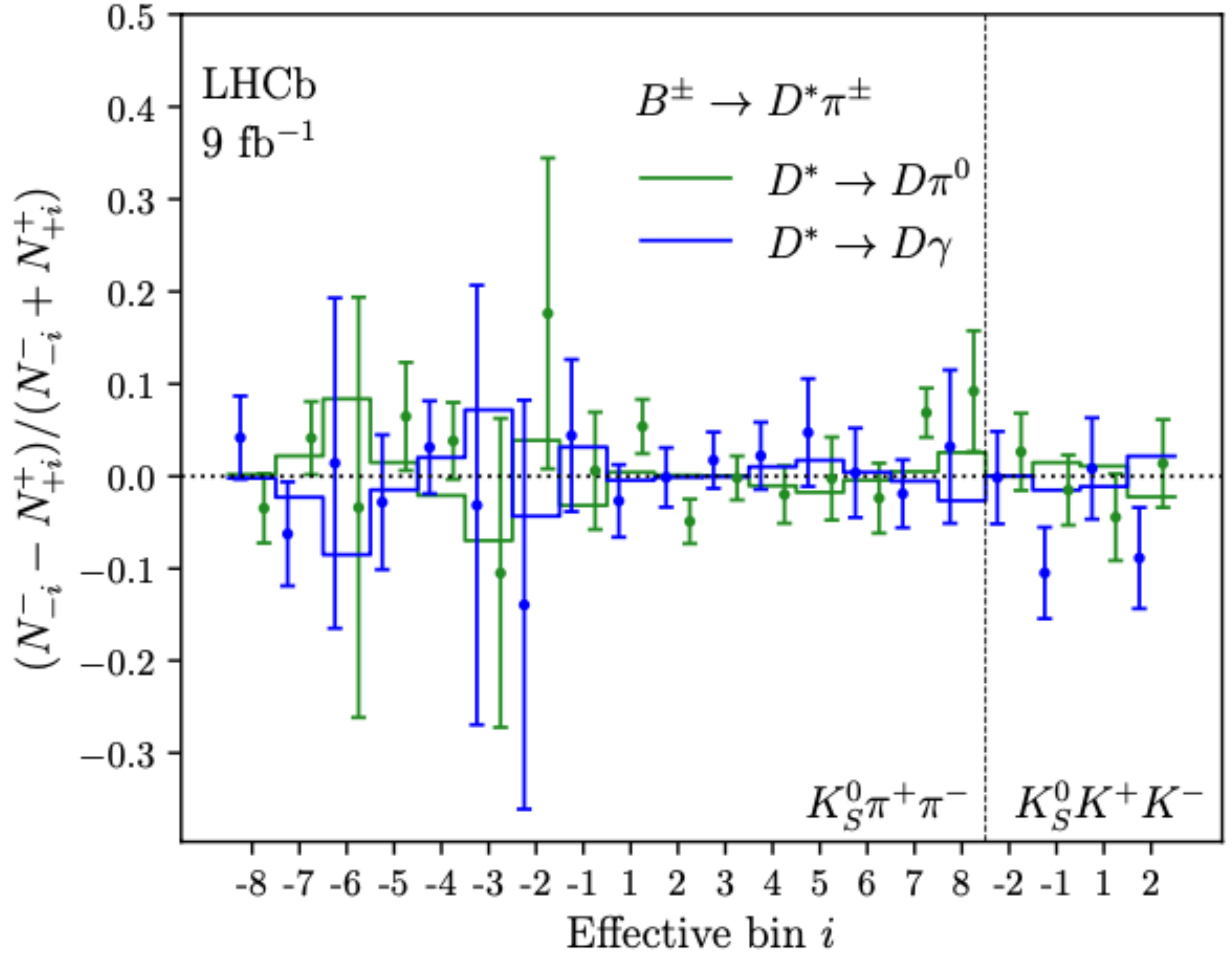
THANK YOU FOR YOUR ATTENTION !

BACKUP

Measurements of the CKM angle γ using $B^{\pm} \to D^{*}h^{\pm}$ channels

JHEP12(2023)013





- Expected per bin asymmetry for $B^{\pm} \to D^{*}K^{\pm}$ and $B^{\pm} \to D^{*}\pi^{\pm}$ obtained by the CP-violating observables (solid lines) and obtained in fit with independent bin yields freely float (errors bars)
- Coherence between the individual bin asymmetries from the fit and the prediction from the CP-violating observables measured in the fit
- Bin asymmetries between $D^{*} \to D\gamma$ and $D^{*} \to D\pi^{0}$ are opposite in sign — Phase shift A(π^0)=-A(γ)

Measurements of the CKM angle γ using $B^{\pm} \rightarrow D^{*}h^{\pm}$ channels

JHEP12(2023)013

- The result of the CP-violating observables:

$$\gamma = (69^{+13}_{-14})^{\circ}$$

$$r_B^{D^*K} = 0.15 \pm 0.03$$

$$\delta_B^{D^*K} = (311 \pm 14)^{\circ}$$

- **Most precise determination of γ with these channels to date and provide good agreement with the world average!**