LHCb实验上CKM矩阵元和相角的测量

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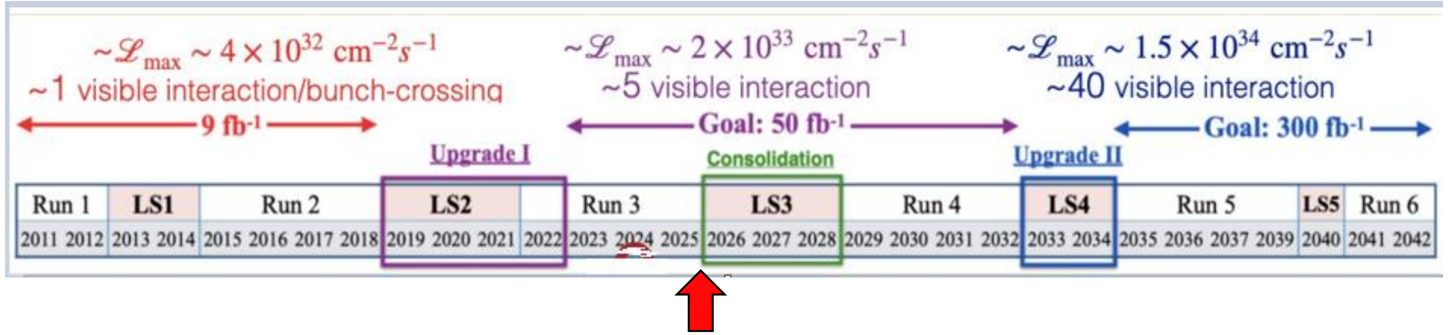
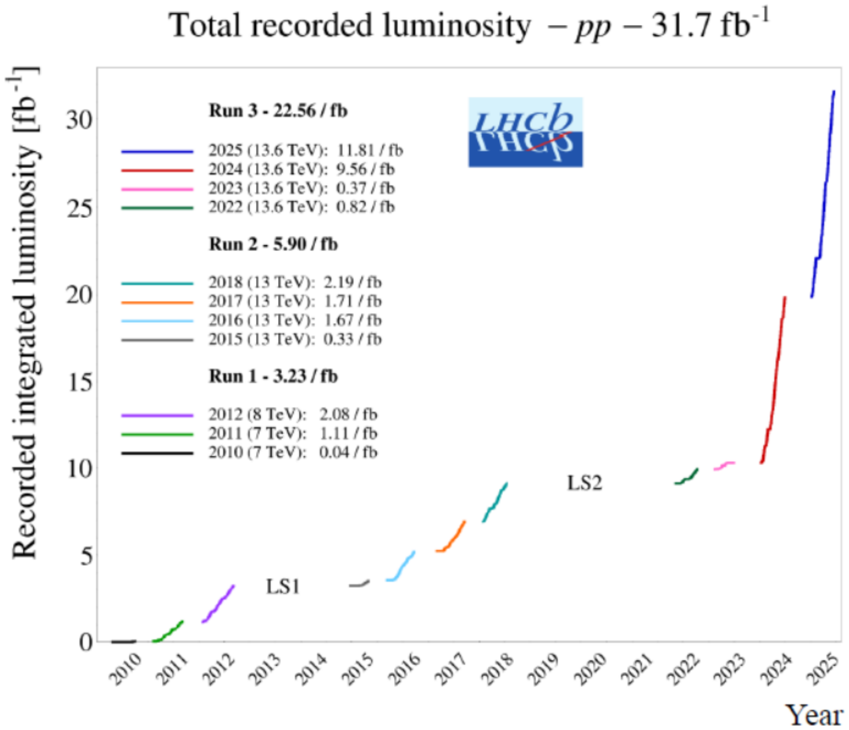
Outline

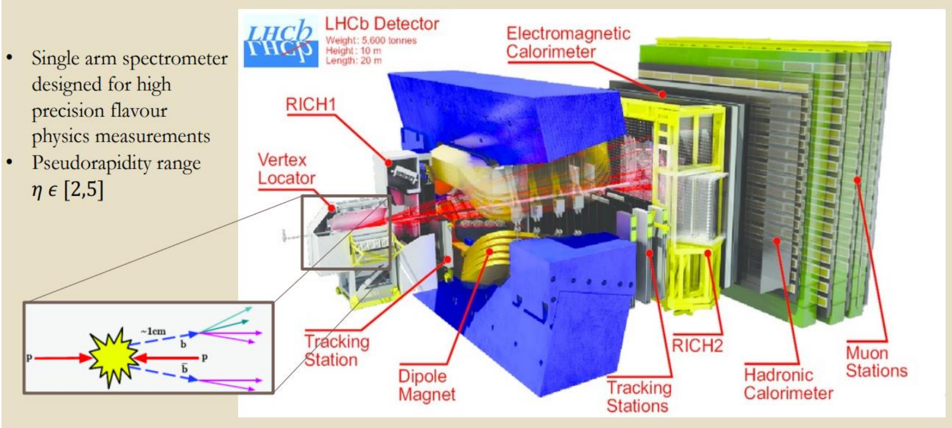
- Introduction
- Measure CKM elements in LHCb
- Measure CKM angle in LHCb
- Summary

LHCb detector and dataset

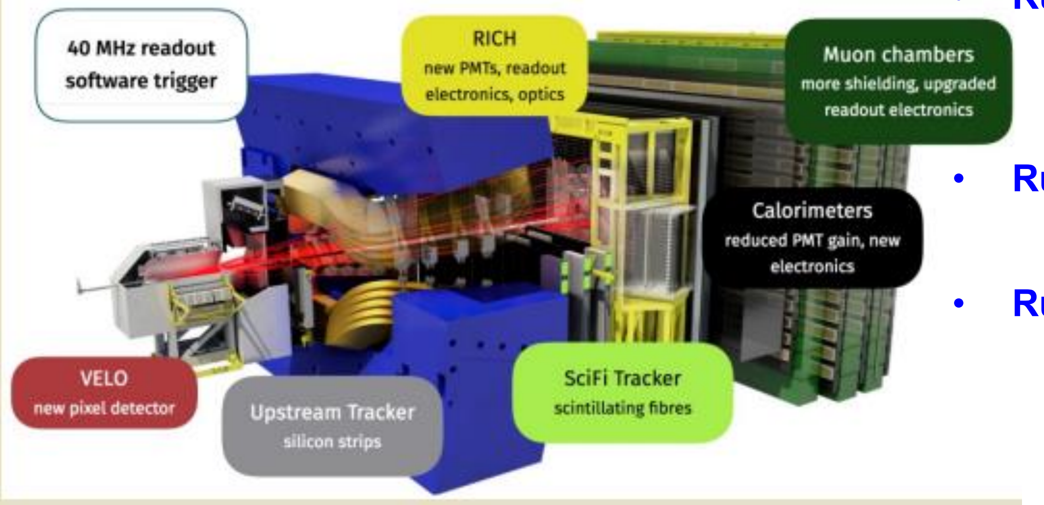




Run 1 & 2 (2011-2018)



New detector for LS2 (now)



- **Run 1:**
  - **2011 (7 TeV): 1 fb^{-1}**
  - **2012 (8 TeV): 2 fb^{-1}**
- **Run 2:**
  - **2015-2018 (13 TeV): 6 fb^{-1}**
- **Run 3:**
  - **2024 alone (13.6 TeV): 9.56 fb^{-1}**
  - **2025 (13.6 TeV): 11.81 fb^{-1}**

CKM matrix elements

- CKM matrix: 3×3 unitary matrix
- Unitarity test remains one of the main directions to probe NP beyond SM
- Precision essential to constrain NP scenarios

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

V_{ud}: from $0^+ \rightarrow 0^+$ nuclear β decays,

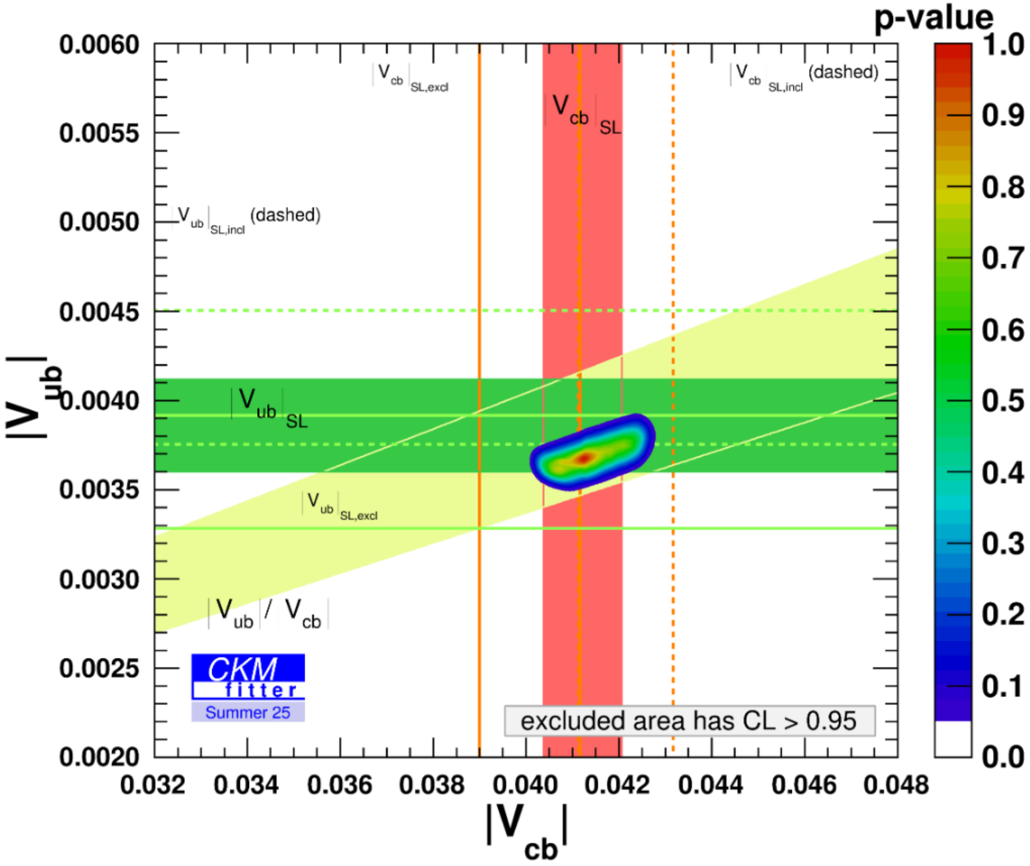
V_{us}: from kaon (semi-) leptonic decay, *LHCb-PAPER-2025-030*

V_{cd} and V_{cs}: from D/D_s (semi-) leptonic decay (see BaiCian's talk),

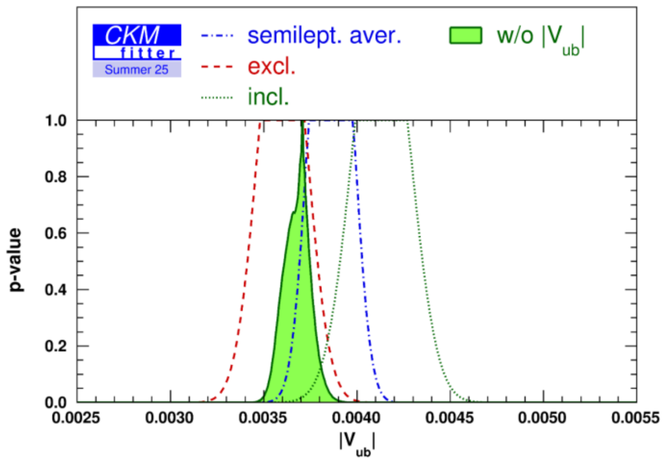
V_{cb} and V_{ub}: from $B \rightarrow X_{u/c} l\nu$

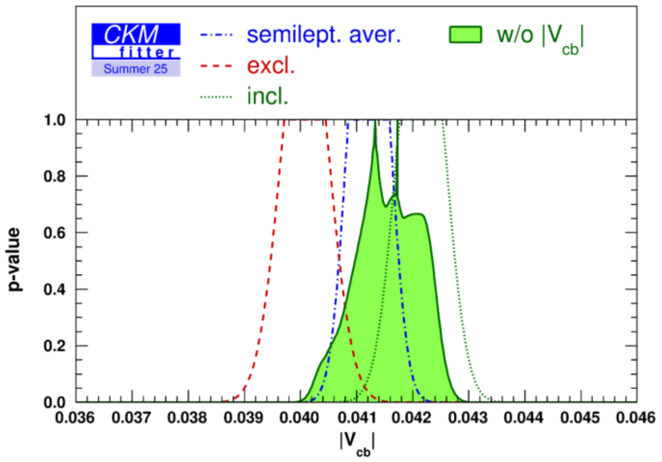
V_{td} and V_{ts}: determined from $B - \bar{B}$ mixing, or loop-mediated rare *K* and *B* decays,

V_{tb}: from top decays



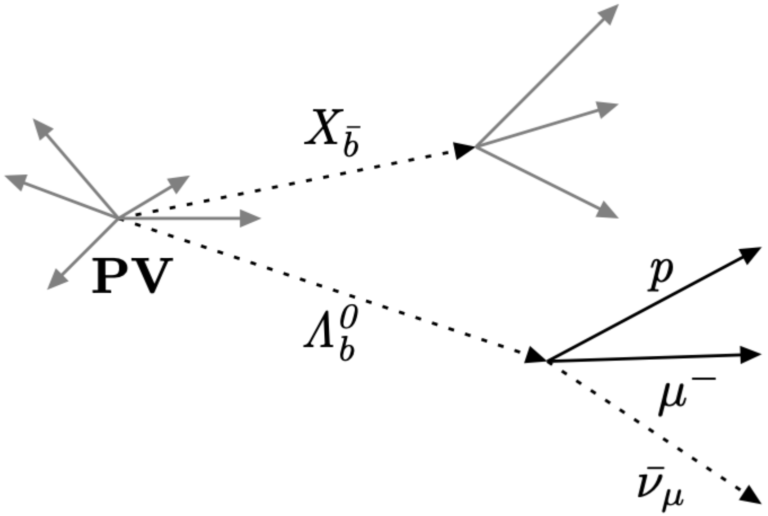
- $|V_{ub}|$ and $|V_{cb}|$ remains one of the main limitations in CKM global fit
- Long standing tension: inclusive vs exclusive
- difficulties in reconstructing missing particles and more precise in measuring ratios in LHCb
- LHCb also plays a leading role





Determination of $|V_{ub}|$ using baryonic decays

Nature Physics 11 (2015) 743



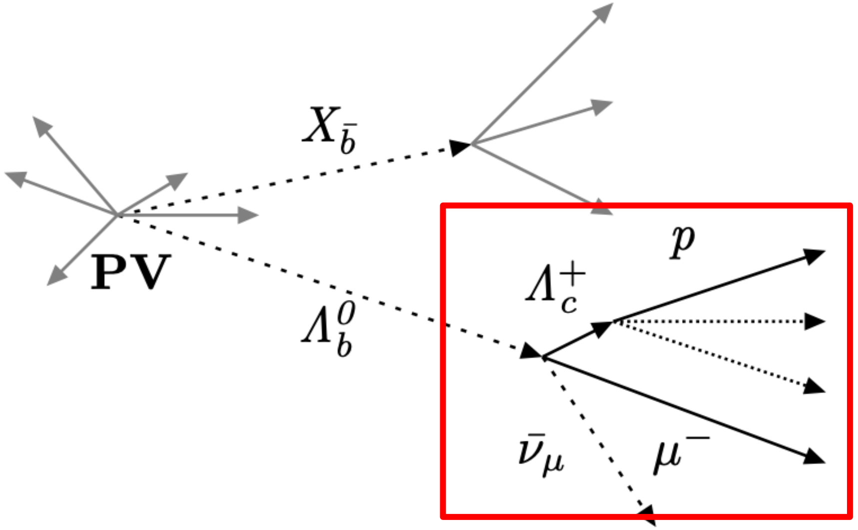
- Dataset: 2 fb^{-1} at $\sqrt{s}$ = 8 TeV (2012)
- Ratio between $|V_{cb}|$ and $|V_{ub}|$ determined using $\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu$ and $\Lambda_b^0 \to \Lambda_c^+\mu^-\bar{\nu}_\mu$

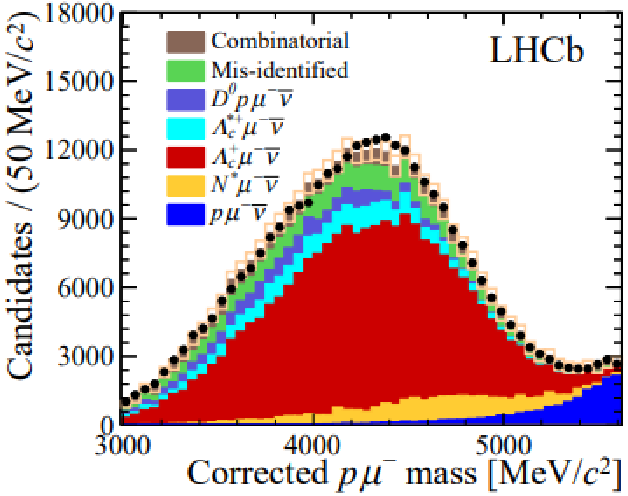
$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = \frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)} R_{\rm FF}$$

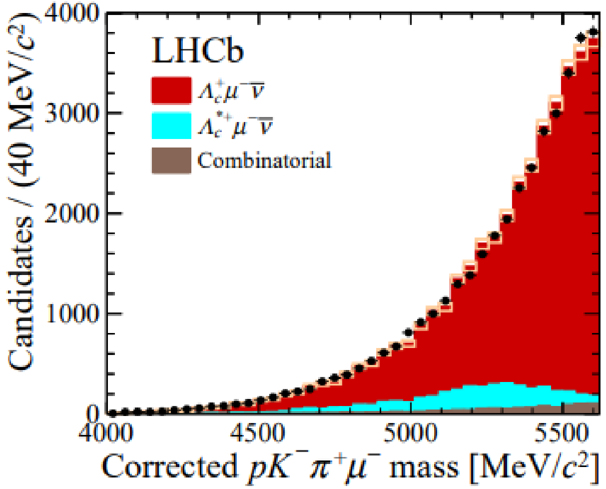
Inputs from LQCD

$$\frac{\mathcal{B}(\Lambda_b^0 \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,{\rm GeV}/c^2}}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)_{q^2>7\,{\rm GeV}/c^2}} = (1.00 \pm 0.04 \pm 0.08)\times 10^{-2}$$

Half systematic from Br($\Lambda_c^+ \to pK^+\pi^-$)

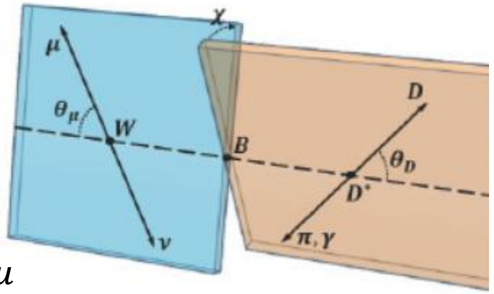




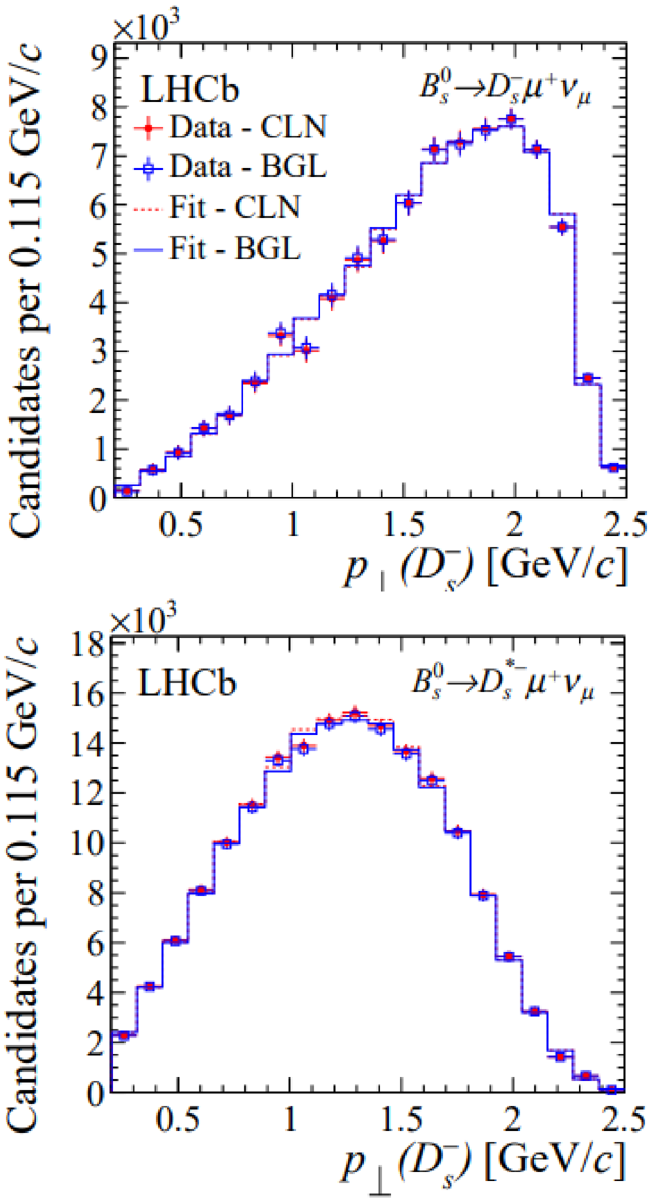


Meausre $|V_{cb}|$ in LHCb

PRD101 (2020) 072004



- Run1 data used (3 fb^{-1})
- Signal modes: $B_s^0 \to D_s^-([KK]_\phi\pi)\mu^+\nu_\mu$ and $B_s^0 \to D_s^{*-}\mu^+\nu_\mu$
- Reference modes: $B^0 \to D^-([KK]_\phi\pi)\mu^+\nu_\mu$ and $B^0 \to D^{*-}\mu^+\nu_\mu$
- either the CLN or the BGL parametrization used to model the form factors
- p⊥(Ds): component of the Ds momentum perpendicular to the Bs flight direction instead of q^2
- $$|V_{cb}|_{\rm CLN} = (41.4 \pm 0.6\,({\rm stat}) \pm 0.9\,({\rm syst}) \pm 1.2\,({\rm ext})) \times 10^{-3}\,,$$
  $$|V_{cb}|_{\rm BGL} = (42.3 \pm 0.8\,({\rm stat}) \pm 0.9\,({\rm syst}) \pm 1.2\,({\rm ext})) \times 10^{-3}\,,$$
- First determinations of $|V_{cb}|$ at a hadron-collider experiment
- First using B_s meson decays



Measurement of $|V_{ub}|/|V_{cb}|$

PRL126 (2021) 081804

- Dataset: 2 fb^{-1} at $\sqrt{s}$ = 8 TeV (2012)
- First observation for $B_s^0 \to K^- \mu^+ \nu_\mu$
- Normalization: $B_s^0 \to D_s^-(KK\pi)\mu^+\nu_\mu$
- $|V_{ub}|/|V_{cb}|$ extraction in two q^2 bins

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} \times \underbrace{\frac{\mathrm{FF}_{B_s^0 \to K^-}}{\mathrm{FF}_{B_s^0 \to D_s^-}}}_{\text{Theory Input}} = \underbrace{\frac{\mathcal{B}(B_s^0 \to K^- \mu^+ \nu_\mu)}{\mathcal{B}(B_s^0 \to D_s^- \mu^+ \nu_\mu)}}_{\text{Experiment}}$$

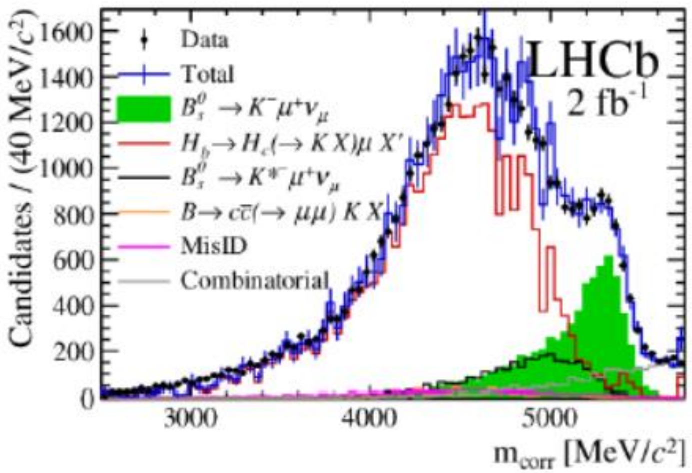
$$= \underbrace{\frac{N_{B_s^0 \to K^- \mu^+ \nu_\mu}}{N_{B_s^0 \to D_s^- \mu^+ \nu_\mu}}}_{\text{Fit}} \times \underbrace{\frac{\varepsilon_{B_s^0 \to K^- \mu^+ \nu_\mu}}{\varepsilon_{B_s^0 \to D_s^- \mu^+ \nu_\mu}}}_{\text{Simulation}} \times \underbrace{\mathcal{B}(D_s^- \to K^- K^+ \pi^-)}_{\text{External input}}$$

$$|V_{ub}|/|V_{cb}| = 0.0607 \pm 0.0015(\text{stat}) \pm 0.0013(\text{syst}) \pm 0.0008(D_s) \pm 0.0030(\text{FF})$$

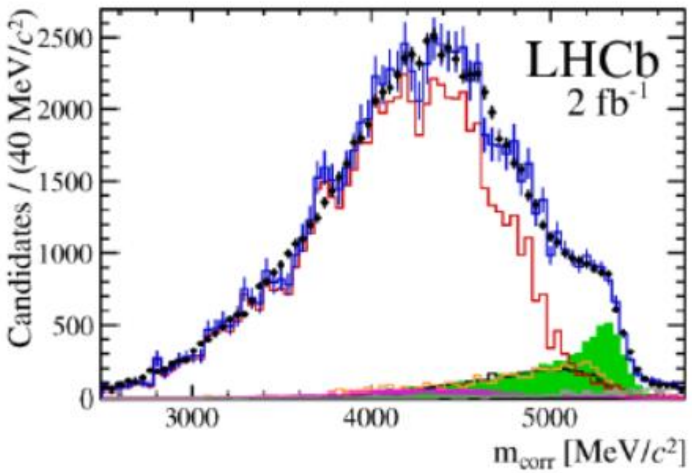
$$|V_{ub}|/|V_{cb}| = 0.0946 \pm 0.0030(\text{stat}) \,^{+0.0024}_{-0.0025}(\text{syst}) \pm 0.0013(D_s) \pm 0.0068(\text{FF})$$

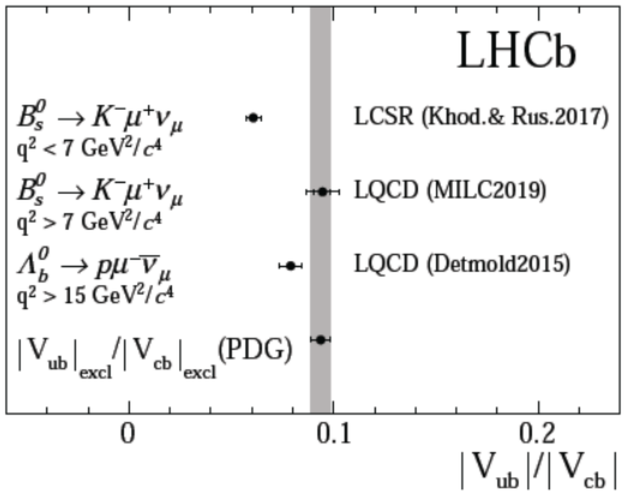
Tension is driven by difference in FF calculation

Signal fit at low q^2



Signal fit at high q^2



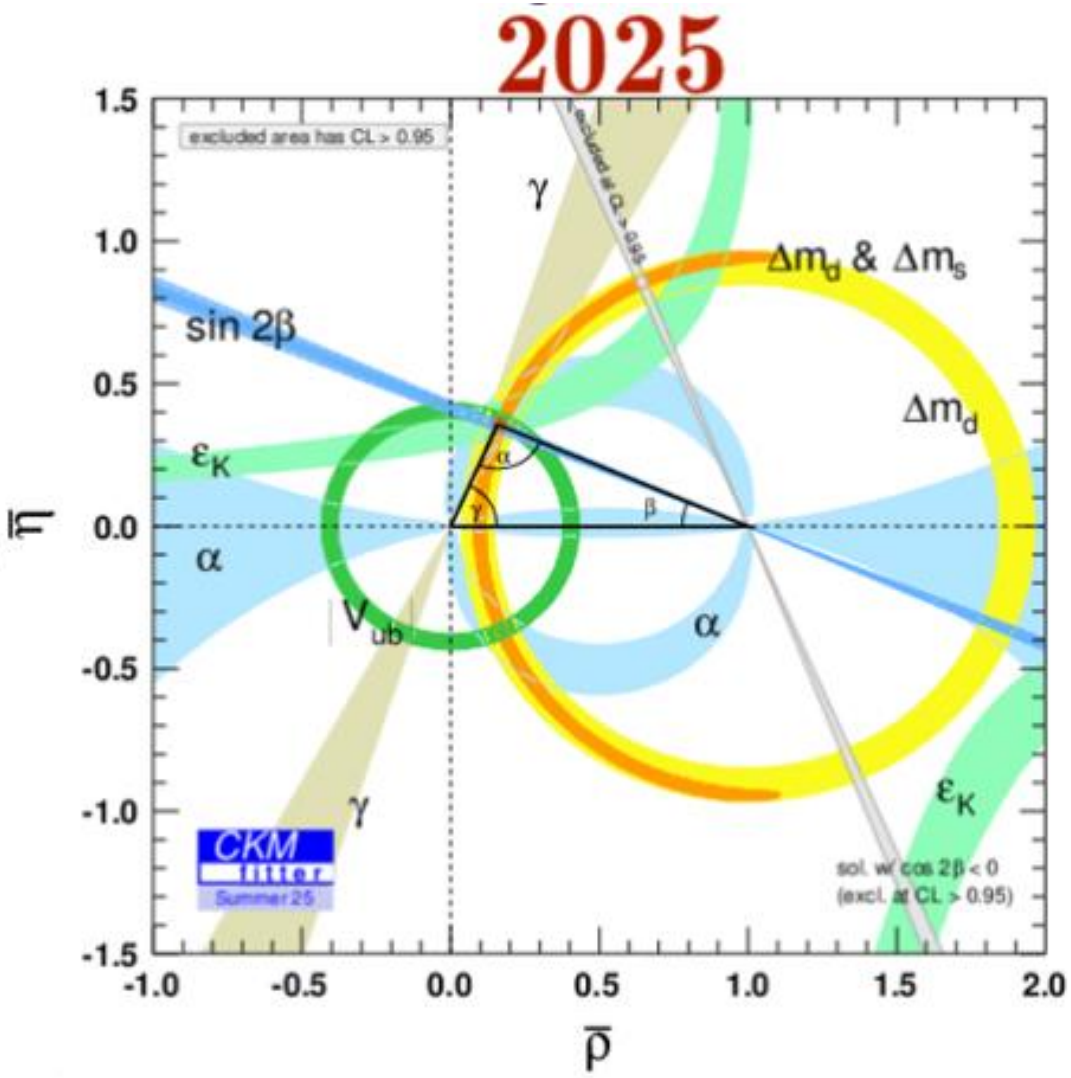


Upcoming measurements at LHCb

- **Extracting |V$_{ub}$| from $B_s^0 \to K^-\mu^+\nu_\mu$ and $B_s^0 \to K^-$ FF parameters with Run 2 data**
  - Measure shape of differential decay rate in eight bins of q^2
- **Extracting |V$_{ub}$| from $B^+ \to \rho^0\mu^+\nu_\mu$ and $B^+ \to \rho^0$ FF parameters with Run 2 data**
  - Measure shape of differential decay rate in 10 bins of q^2
- **Extracting |V$_{ub}$|/|V$_{cb}$| from $B_c^+ \to D^{(*)0}\mu^+\nu_\mu$ with Run 2 data**
  - Normalize to $B_c^+ \to J/\psi\mu^+\nu_\mu$
  - Profit from LQCD $B_c^+ \to D^0$ FF across full q^2 *Phys. Rev. D 105, 014503 (2022)*
- **Extracting |V$_{cb}$| form $\Lambda_b^0 \to \Lambda_c^+\mu^-\bar{\nu}_\mu$ with Run 2 data**
  - Measure shape of differential decay rate
- **Extracting $B^0 \to D^{*-}$ FF from$B^0 \to D^{*-}\mu^+\nu_\mu$ using Run 2 data**

Many exciting Run 2 results upcoming
Expect more data in Run3

CKM angle



CKM matrix unitarity: key test of the SM

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

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

Latest results from HFLAV:

$$\alpha/\phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) = (84.1^{+3.7}_{-3.0})^o$$

$$\beta/\phi_1 = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) = (22.63^{+0.45}_{-0.44})^o$$

$$\gamma/\phi_3 = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right) = (66.4^{+2.7}_{-2.8})^o$$

measure β/ϕ_1 angle

- Time dependent *CP*-violation → β/ϕ_1 angle
- Golden decay: $B^0 \to J/\psi K^0$

$\sin 2\beta = 0.709 \pm 0.011$

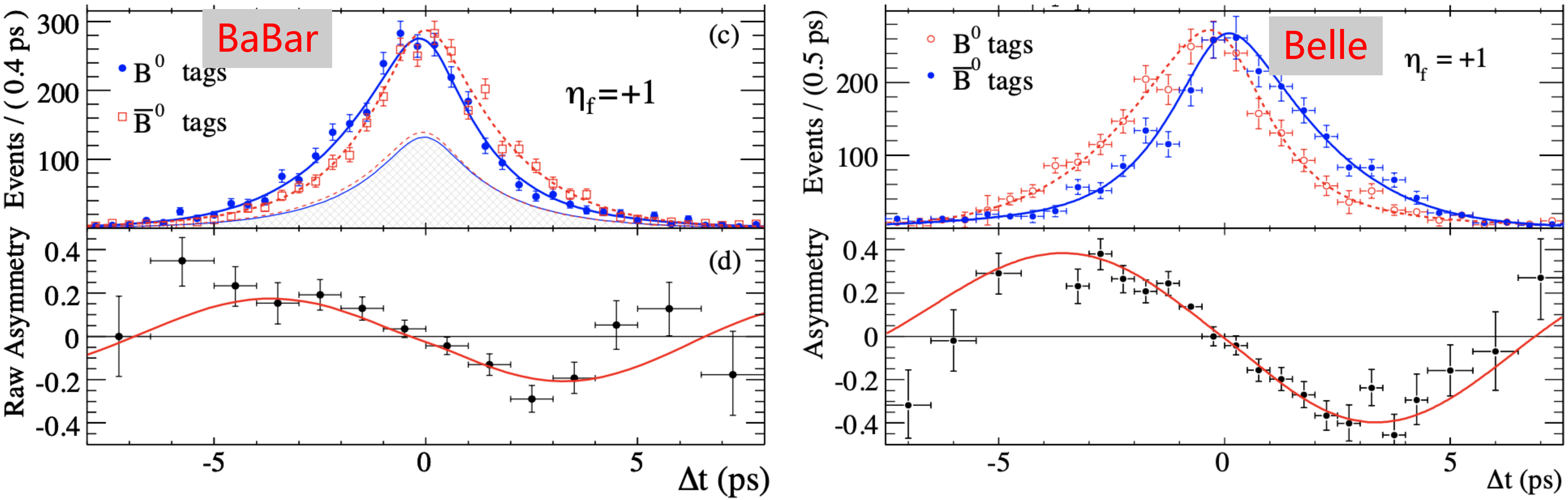
Dominated by LHCb run1&2
PRL132 (2024) 021801

$$A_{f_{CP}}(t) = \frac{\Gamma(\bar{B}^0(t) \to f_{CP}) - \Gamma(B^0(t) \to f_{CP})}{\Gamma(\bar{B}^0(t) \to f_{CP}) + \Gamma(B^0(t) \to f_{CP})}$$

$$\propto S_f \sin(\Delta m_d t) - C_f \cos(\Delta m_d t)$$

$$\approx \eta_f \sin 2\beta \sin(\Delta m_d t)$$

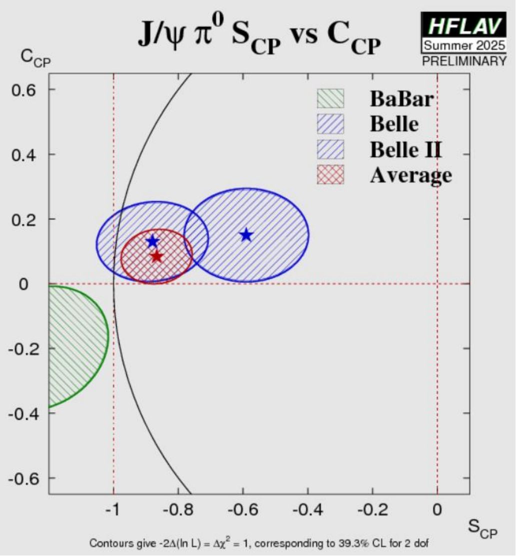
Penguin amplitude ~λ^2-suppressed

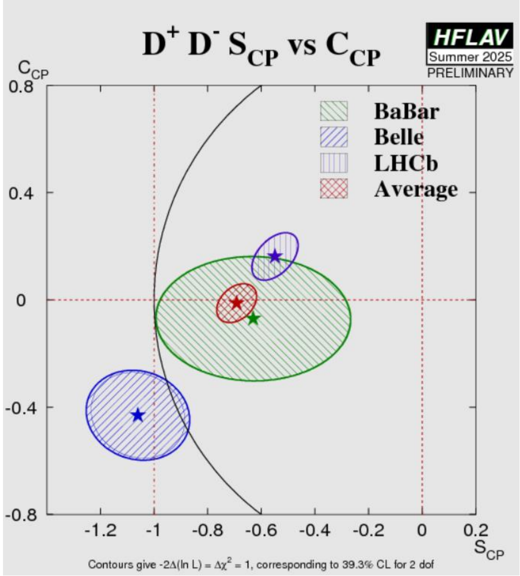


measure β/ϕ_1 via $b \to c\bar{c}d$ decay

- In $b \to c\bar{c}d$: penguin amplitude is large (~λ)
- resulting in $S_f \neq -\eta_f$ and $C_f \neq 0$
- $B^0 \to J/\psi\pi^0,\ J/\psi\rho^0, D^{(*)+}D^{(*)-}$ modes studied

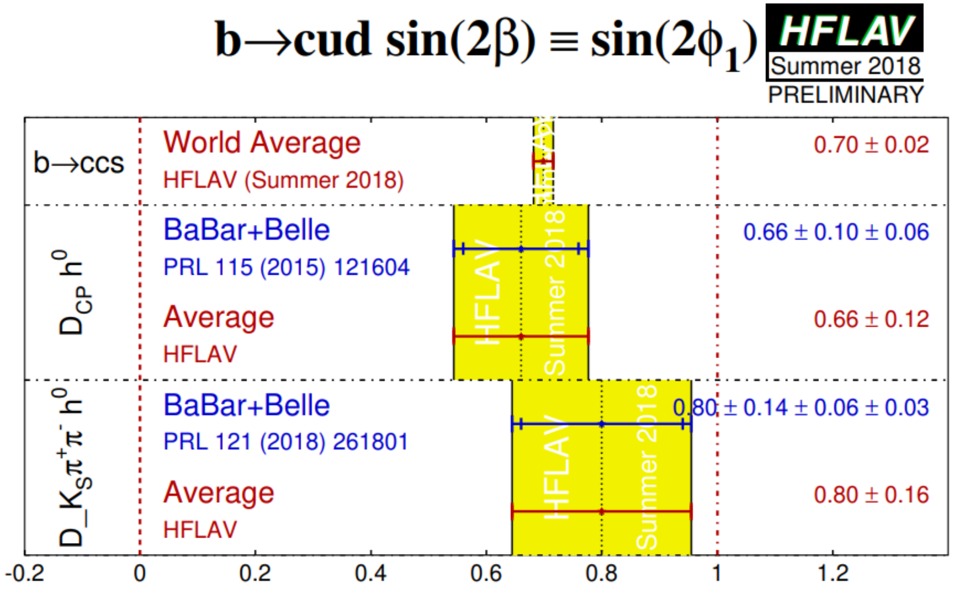
  JHEP 01 (2025) 061
  PLB 742 (2015) 38
- consistent with results from B^0 charmonium K^0 decays
- C_f's are consistent with zero, the uncertainties are sizable



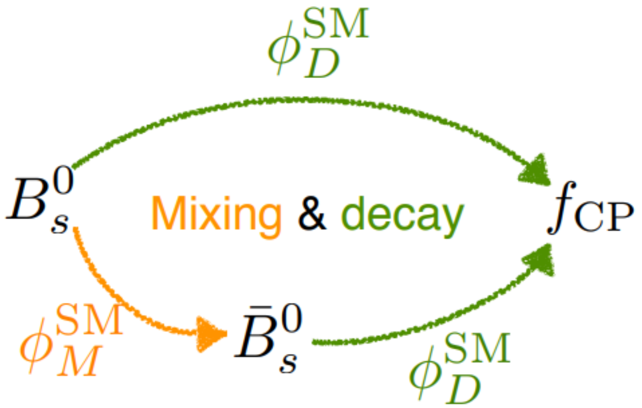


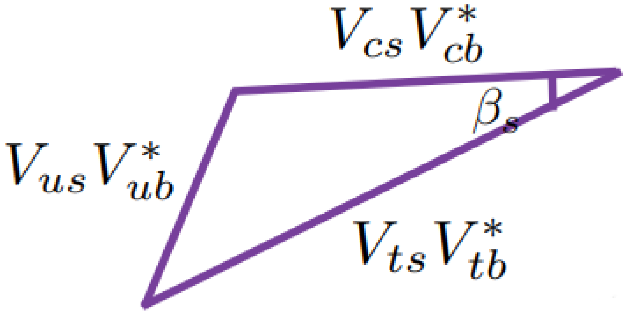
β/ϕ_1 in $B^0 \to \bar{D}^{0(*)}h$ ($b \to c\bar{u}d$) decay

- $b \to c\bar{u}d$ transitions
  - Penguin free
  - Measure $sin2\beta$ and $cos2\beta$ at same time
- Time-dependent analysis
  - $\bar{D} \to CP$
  - $\bar{D} \to K_S^0\pi^+\pi^-$ (Dalitz analysis)
- average of joint analyses of *BABAR* and Belle
- $\sin 2\beta = 0.71 \pm 0.09$
- LHCb run1&2 result come out soon
- Also $b \to q\bar{q}d$ penguin-dominated decays (many works in Belle & Babar), sensitive to effects from virtual new physics particles,



ϕ_s in $b \to c\bar{c}s$ Transition

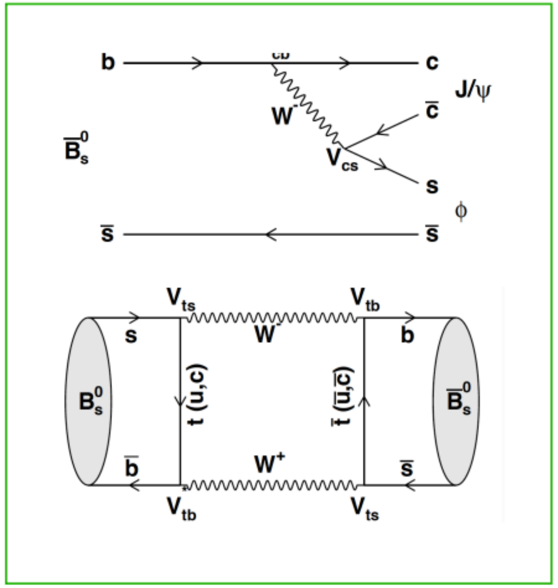




- ϕ_s mixing-induced CPV phase in B_s^0 decay through $b \to c\bar{c}s$ transitions

$$\phi_s^{meas.} = -2\beta_s + \delta\phi_s^{peng} + \delta\phi_s^{NP}$$

$$A_{CP}(t) = \frac{\Gamma_{\bar{B}_s^0\to f}(t) - \Gamma_{B_s^0\to f}(t)}{\Gamma_{\bar{B}_s^0\to f}(t) + \Gamma_{B_s^0\to f}(t)} \propto -\eta_f \sin 2\beta_s \sin(\Delta M_s t)$$



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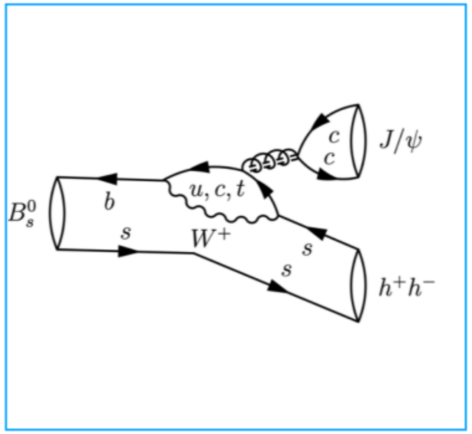

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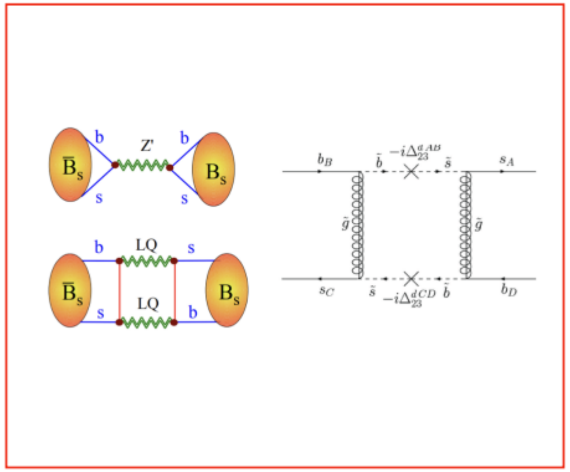


$2\beta_s$:

$36.8^{+0.9}_{-0.6}$ mrad [CKMfitter]

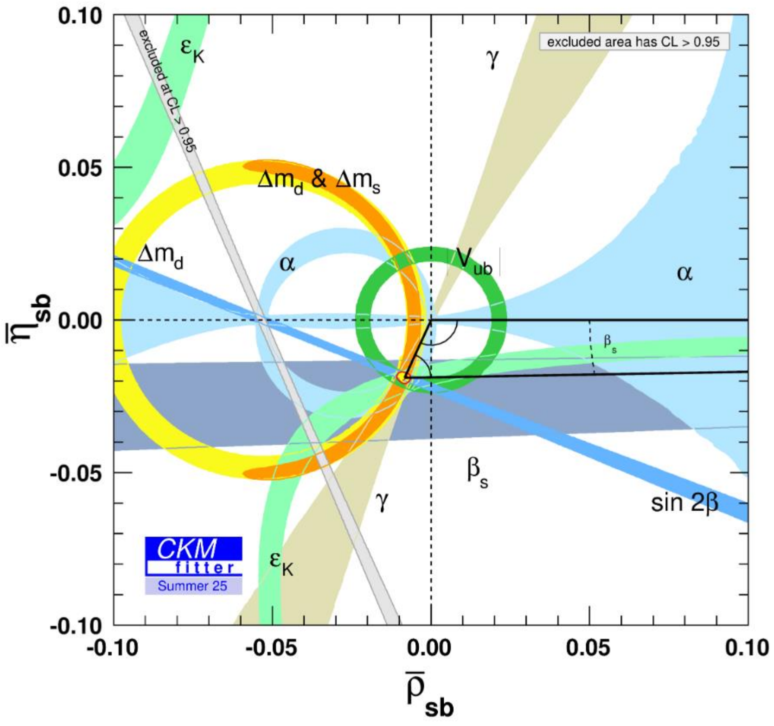
(37 ± 1) mrad [UTFIT]

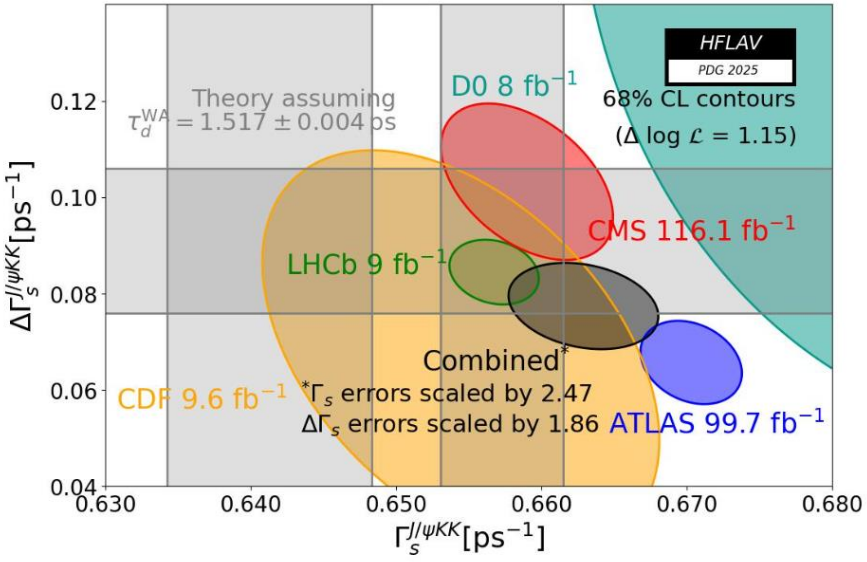
Status of ϕ_s Measurements

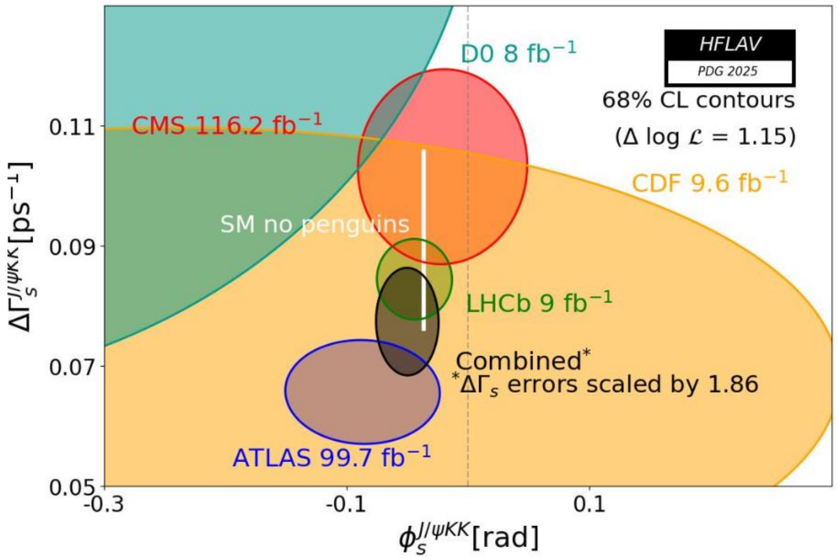
- $B_s \to J/\psi\phi$: Golden mode
  - Measure ϕ_s, $\Delta\Gamma$, Γ_s-Γ_d
- Experimental Combination (CDF, D0, ATLAS, CMS, LHCb):

$\phi_s^{c\bar{c}s} = (-50 \pm 17)$ **mrad** $\quad \Delta\Gamma_s = (0.077 \pm 0.006)$ **ps^{-1}**

LHCb dominated
PRL 132 (2024) 051802







CPV parameters in $B_s \to J/\psi \bar{K}^{*0}$

- $\phi_s^{meas.} = -2\beta_s + \delta\phi_s^{peng} + \delta\phi_s^{NP}$

channel	Quark transition	Strength of tree	Strength of penguin
$B_s^0 \to J/\psi\,\phi$	$b \to ccs$	$\sim\lambda^2$	$\sim\lambda^4$
$B_s^0 \to J/\psi\,\bar{K}^{*0}$	$b \to ccd$	$\sim\lambda^4$	$\sim\lambda^4$

- Angular Analysis

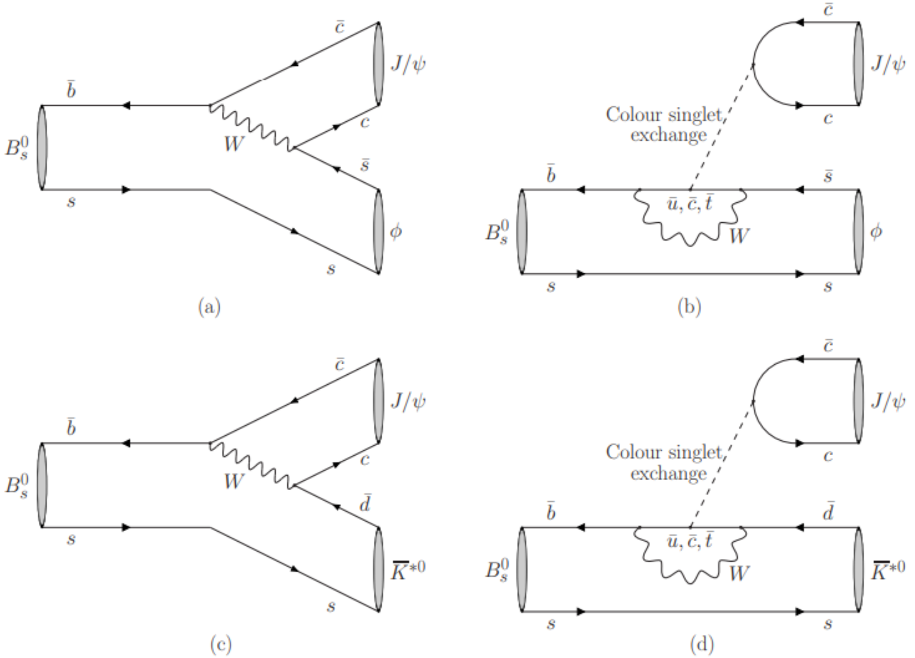
$$A\left(B_s^0 \to (J/\psi\,\overline{K}^{*0})_i\right) = -\lambda\mathcal{A}_i\left[1 - a_i e^{i\theta_i} e^{i\gamma}\right]$$

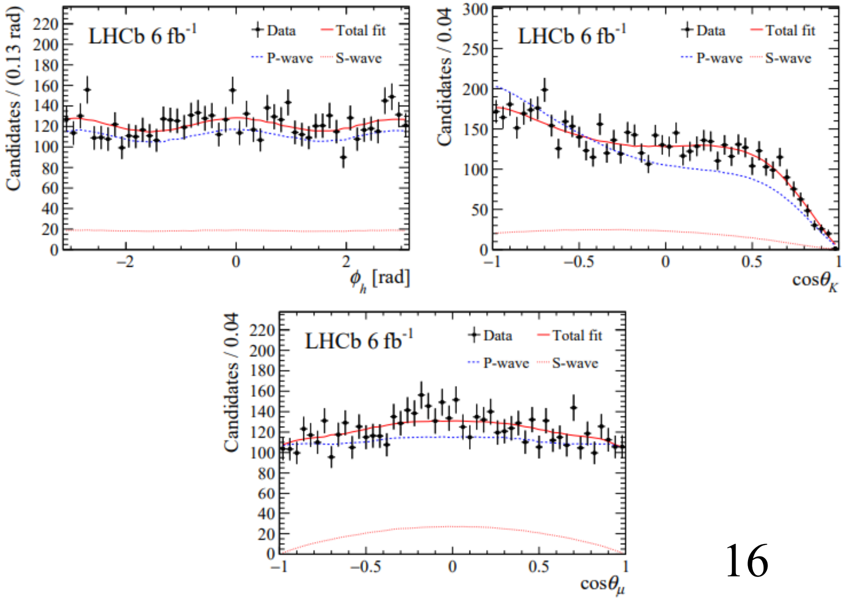
$$A\left(B_s^0 \to (J/\psi\,\phi)_i\right) = \left(1 - \frac{\lambda^2}{2}\right)\mathcal{A}'_i\left[1 + \epsilon a'_i e^{i\theta'_i} e^{i\gamma}\right]$$

- Assuming $a'_i = a_i\,, \quad \theta'_i = \theta_i$
- Run1 result (*JHEP 11 (2015) 082*)

$$\Delta\phi_{s,0}^{J/\psi\phi} = 0.000^{+0.009}_{-0.011}\,(\text{stat})\ {}^{+0.004}_{-0.009}\,(\text{syst})\text{ rad}\,,$$
$$\Delta\phi_{s,\parallel}^{J/\psi\phi} = 0.001^{+0.010}_{-0.014}\,(\text{stat}) \pm 0.008\,(\text{syst})\text{ rad}\,,$$
$$\Delta\phi_{s,\perp}^{J/\psi\phi} = 0.003^{+0.010}_{-0.014}\,(\text{stat}) \pm 0.008\,(\text{syst})\text{ rad}\,.$$

- Run2 analysis published *JHEP10(2025)173*



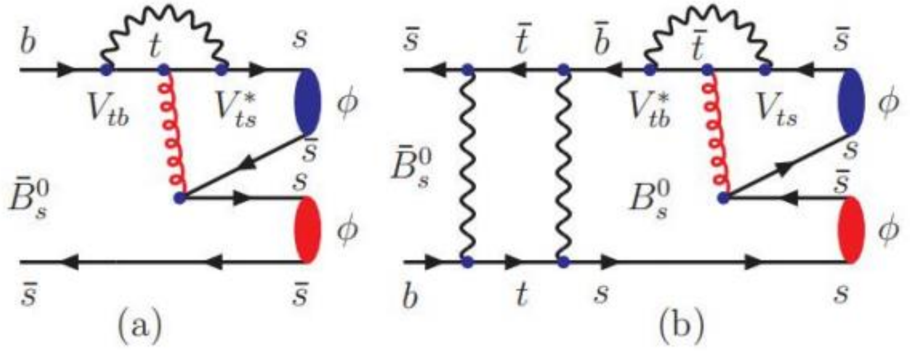


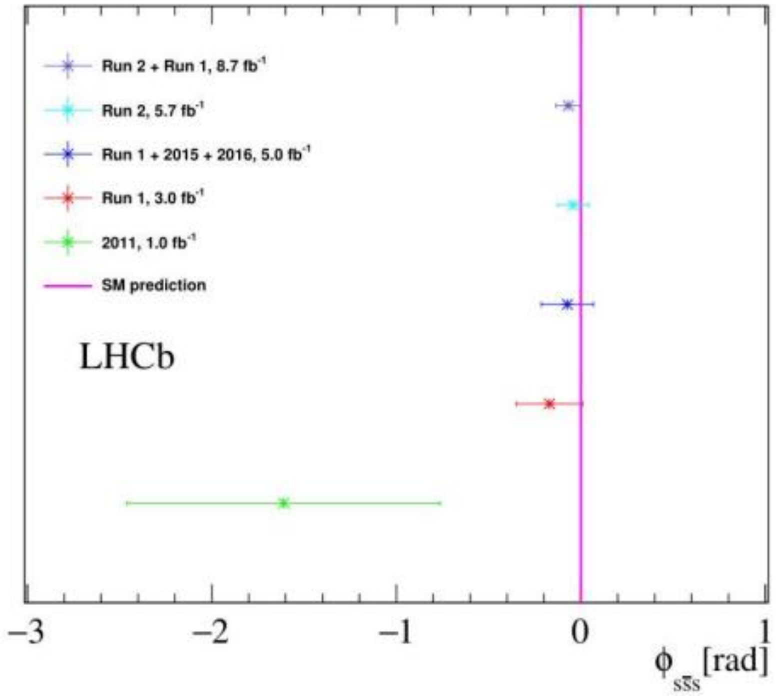
CPV parameters in $B_s \to \phi\phi$

PRL 131 (2023) 171802

- $B_s \to \phi\phi$: golden channel to study CPV in $b \to s$ decays
  - Tiny CPV in SM
  - Sensitive to NP in B_s mixing and $b \to s$ decay
- CP violation observables from flavor-tagged time-dependent angular analysis
  - CP violating phase $\phi_{s,i}^{s\bar{s}s}$ and direct CP violation parameter $\lambda_i = |\frac{\bar{A}_i}{A_i}|$
  - SM predictions: $\phi_{s,i}^{s\bar{s}s} \approx 0$ and $\lambda_i \approx 1$ for $i = 0, \perp, \parallel$
  - Polarization-independent fit: common $\phi_s^{s\bar{s}s}$ and λ for different Polarization
- Full Run 2 data, and make a combination with Run 1
  - Consistent with SM expectation
  - No sign of polarization-dependence observed
  - Most precise measurement of time-dependent CP violation in $b \to s$ decay

$$\phi_s^{s\bar{s}s} = -0.074 \pm 0.069 \text{ rad}$$
$$|\lambda| = 1.009 \pm 0.030$$





How to measure α/ϕ_2

- Typical decay: $B^0 \to \pi^+\pi^-\pi^0, \pi\pi, \rho\rho$ ...

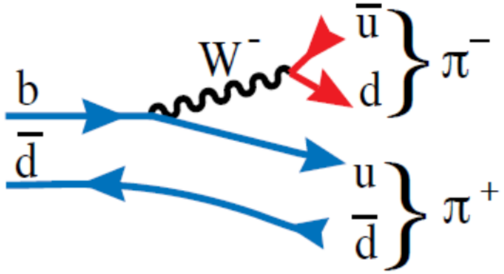
- If $B^0 \to \pi^+\pi^-$ only determined by b→u tree diagram, similar to β

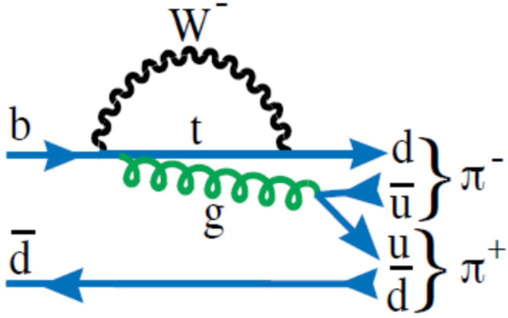
- $B^0 \to \pi^+\pi^-$ penguin contribution same order to tree diagram

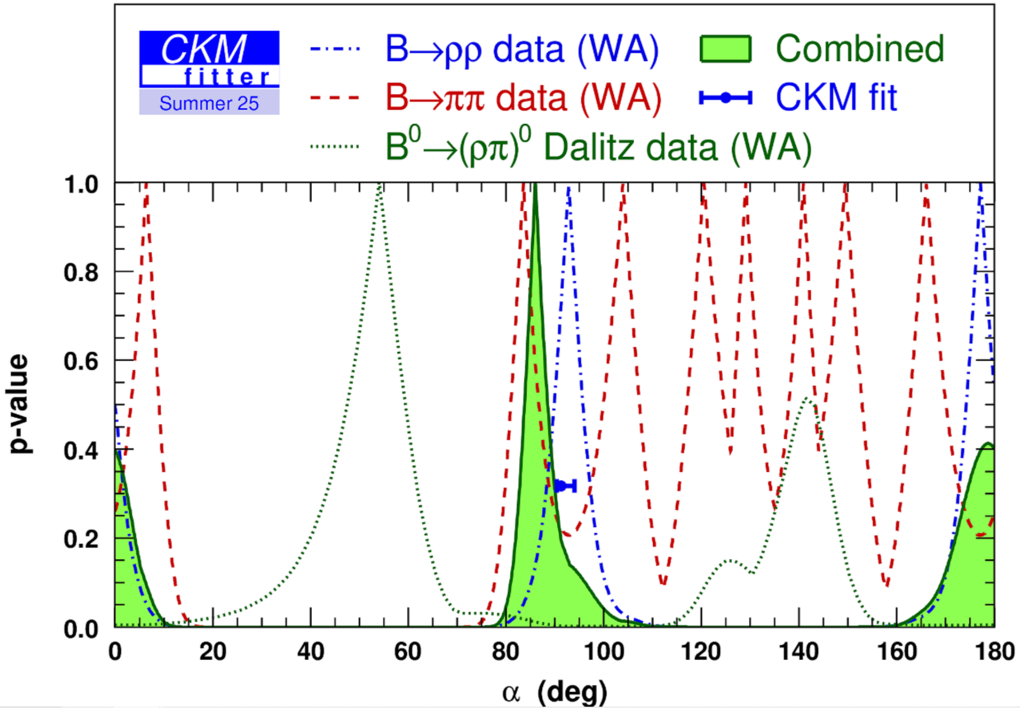
- M. Gronau & D. London: Isospin analysis of CP asymmetries in B decays, simultaneously measure $B_d^0 \to \pi^+\pi^-$, $B_d^0 \to \pi^0\pi^0$ and $B_u^+ \to \pi^+\pi^0$ *PRL 65 (1990) 3381*

- Other methods（e.g. $B \to \rho^{+/0}\rho^{-/0}$ ）

- Limited to the statistics, still much room for improvement in accuracy of α

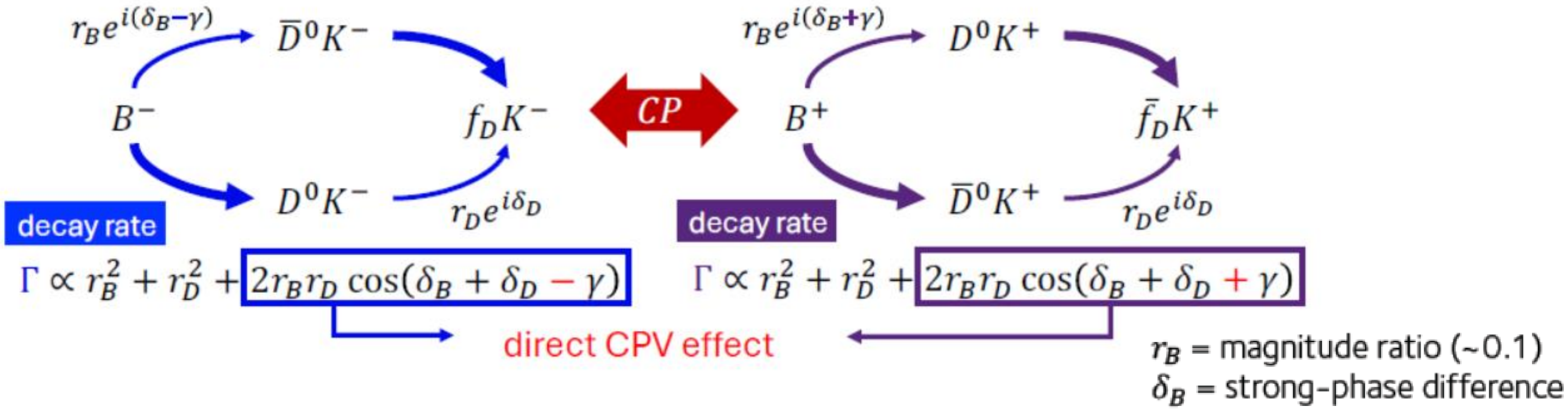






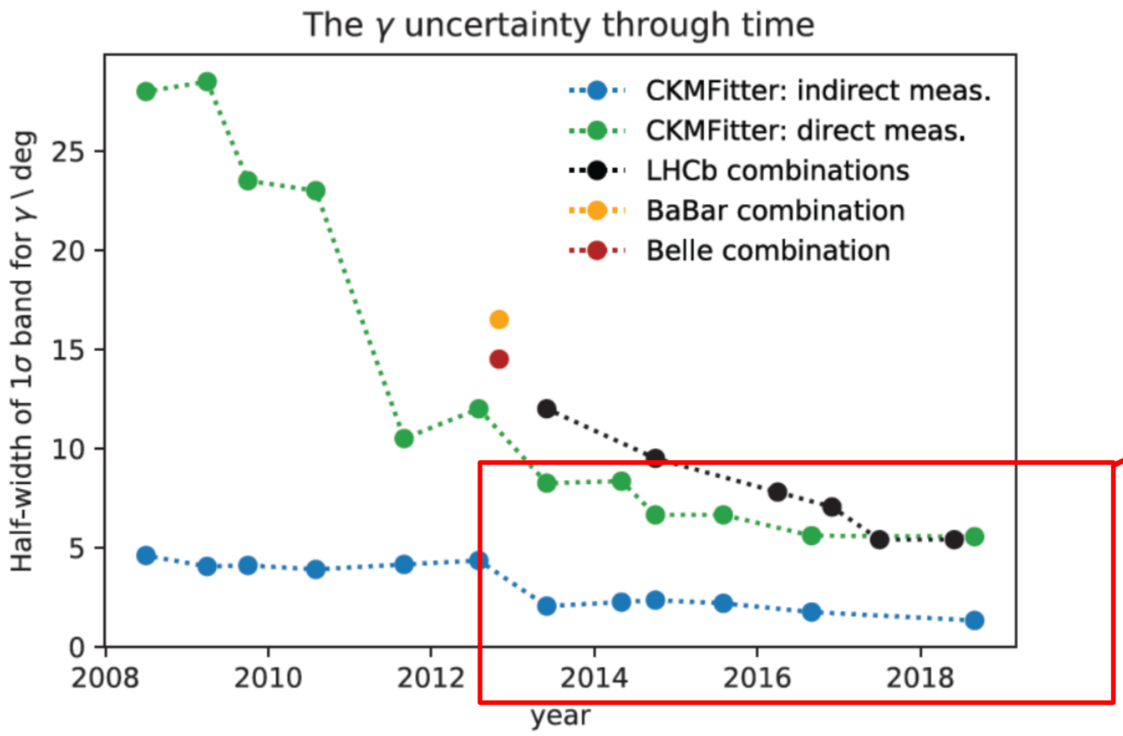
How to measure γ/ϕ_3: direct CPV

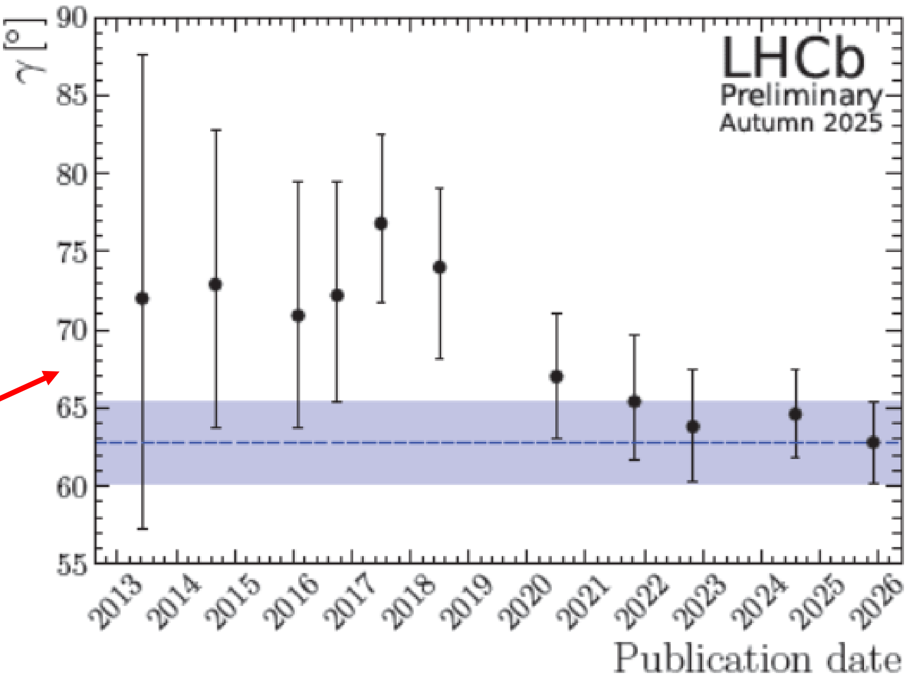
- Interference between favoured $b \to c$ and suppressed $b \to u$ decay amplitude
- tree-level decays, theoretically clean($\delta\gamma/\gamma < 10^{-7}$) *JHEP 1401(2014)051*
- Ideal decays: B→DK (clean background, large branching fraction)



- Different method according to *D* decay modes
  - GLW method: CP modes such as $D \to K^+K^-, \pi^+\pi^-$
  - ADS method: Flavor modes such as $D \to K\pi,\ K\pi\pi^0$
  - BPGGSZ method: $D \to K_s\pi\pi/K_sKK$ (golden mode)

Evolution of γ results

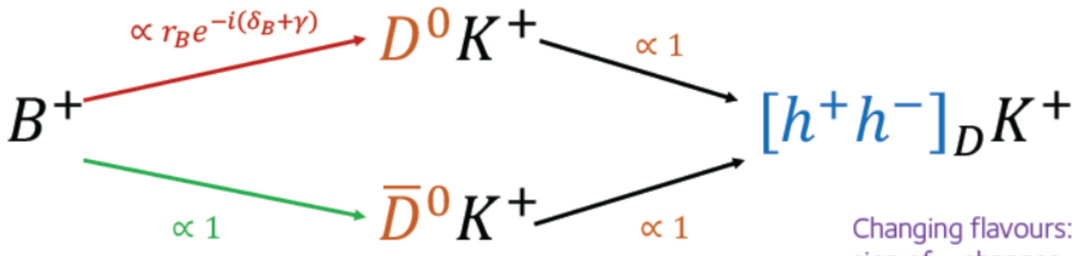




- The precision of γ improved significantly over the past two decades
- LHCb dominates current world averages of direct γ measurements
- Many more modes still need to add
- Need *D* strong parameters from charm factory as input (see BaiCian's talk)

GLW method [1,2]

- D (quasi-)CP-eigenstate states such as D→K^+K^-,$\pi^+\pi^-$,$\pi^+\pi^-\pi^0$…



Changing flavours: sign of γ changes

$$A(B^+ \to [h^+h^-]_D K^+) \propto 1 + r_B e^{-i(\delta_B+\gamma)}$$
$$A(B^- \to [h^+h^-]_D K^-) \propto 1 + r_B e^{-i(\delta_B-\gamma)}$$

- Use the yields of B+ and B- to construct observables related to γ

$$A^f = \frac{N(B^- \to f_D K^-) - N(B^+ \to f_D K^+)}{N(B^- \to f_D K^-) - N(B^+ \to f_D K^+)} = \frac{2\kappa r_B sin\delta_B sin\gamma}{R^f}$$

$$R^f = \frac{N(B^- \to f_D K^-) - N(B^+ \to f_D K^+)}{N(B^- \to [K\pi]_D K^-) - N(B^+ \to [K\pi]_D K^+)} = 1 + r_B^2 + 2\kappa r_B cos\delta_B cos\gamma$$

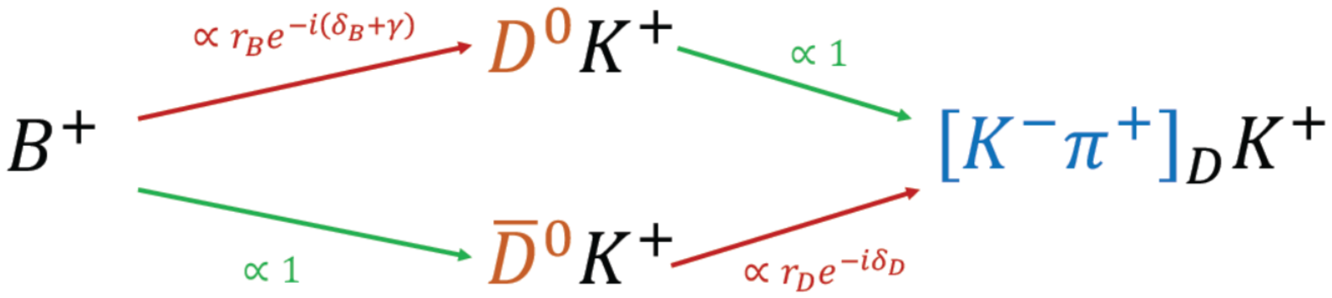
insert a factor of (κ=2F_+-1) before interference terms (F_+=CP even content), need charm input

Notice r_B/δ_B need input

[1] M. Gronau and D. Wyler, Phys. Lett. B265 (1991) 172
[2] M. Gronau and D. London, Phys. Lett. B253 (1991) 483

ADS method[1,2]

- Consider the Cabibbo-favored decay $D^0 \rightarrow K^- \pi^+$ and doubly-Cabibbo-suppressed decay $D^0 \rightarrow K^+ \pi^-$



- r_B/δ_B can be obtained directly, but external input r_D/δ_D

$$\Gamma(B^\pm \rightarrow f_D K^\pm) \propto r_B^2 + r_D^2 + 2R_f r_B r_D \cos(\delta_B + \delta_D \pm \gamma)$$
$$\Gamma(B^\pm \rightarrow \bar{f}_D K^\pm) \propto 1 + r_B^2 r_D^2 + 2R_f r_B r_D \cos(\delta_B - \delta_D \pm \gamma)$$

Need inputs from charm factory

$$R_{K3\pi} e^{-i\delta_{K3\pi}} = \frac{\int A_{K^-3\pi}(x) A_{K^+3\pi}(x)\, dx}{A_{K^-3\pi}(x) A_{K^+3\pi}(x)}$$

- For $K3\pi$ mode, coherence factor $R_{K3\pi}$ and $\delta_{K3\pi}$ averaged over phase space not good for whole space

[1] D. Atwood, I. Dunietz, and A. Soni, Phys. Rev. Lett. 78 (1997) 3257
[2] D. Atwood, I. Dunietz, and A. Soni , Phys. Rev. D63 (2001) 036005

γ from $B^{\pm} \to D[K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\mp}]h^{\pm}$ decays

- Large CPV observed in local bins!

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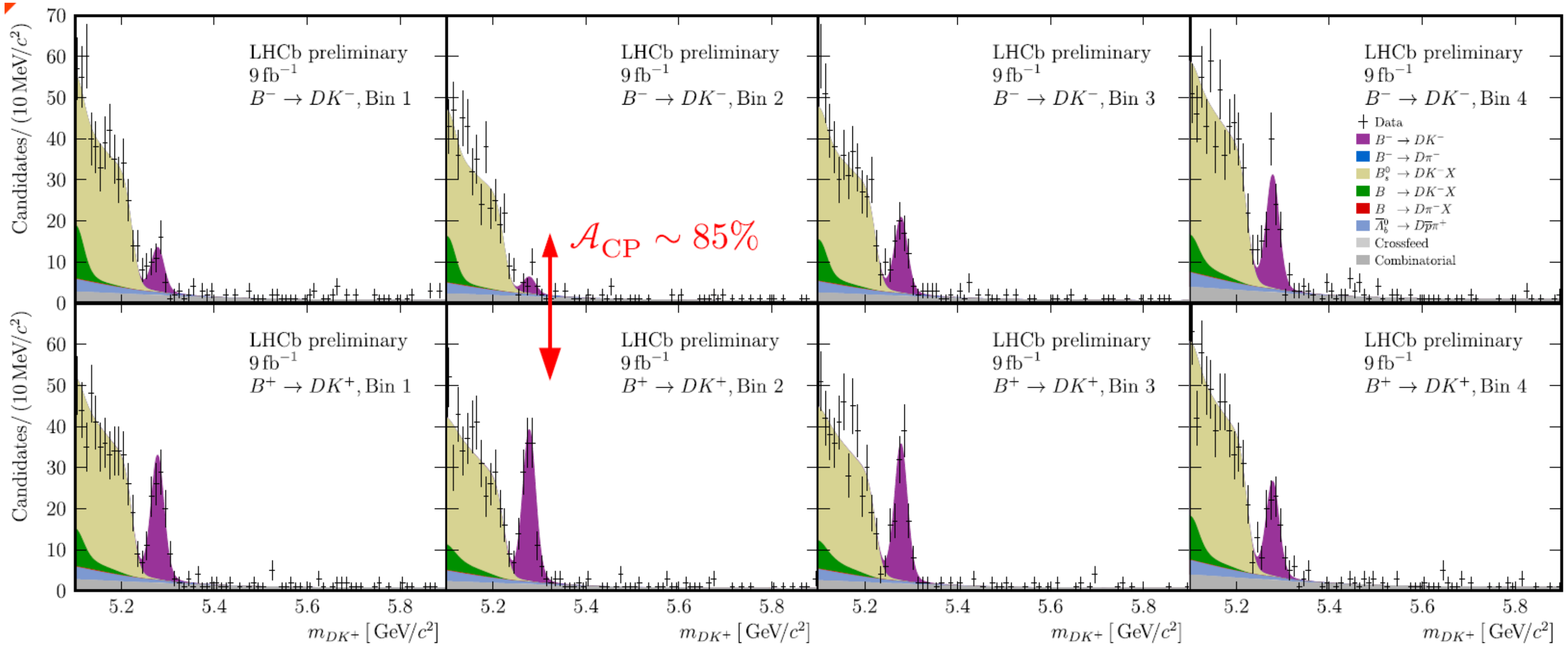
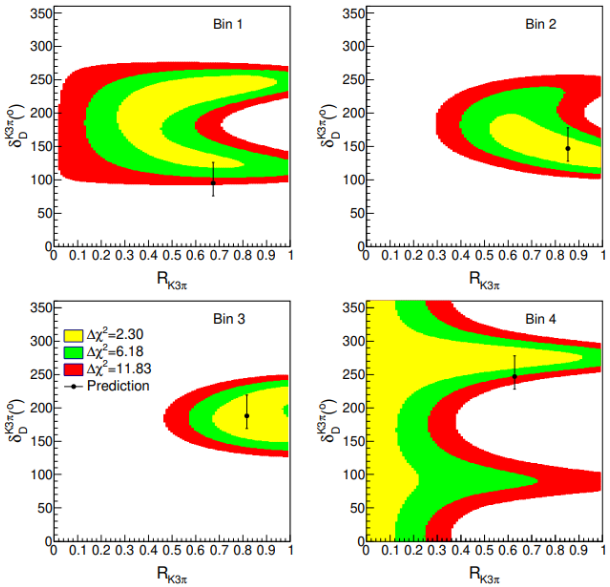




$$\gamma = \left(54.8 \, {}^{+6.0}_{-5.8} \, {}^{+0.6}_{-0.6} \, {}^{+6.7}_{-4.3}\right)^{\circ}$$

Comparable to golden mode!

Large expected improvement from incoming 20fb^{-1} of BESIII ψ(3770) data

BPGGSZ method

- Golden mode: D→$K_s\pi\pi/K_sKK$ (large statistic, large r_D)
  - Model-dependent method (not used now)
  - Model-independent binned method (BPGGSZ method[1])
- Binned Dalitz plane according to δ_D, measure $B^\pm$ yields in each bins
  - Sensitivity from **phase-space distribution**, not overall asymmetries → not impacted by production/detection asymmetries
  - LHCb latest $\boldsymbol{K_s hh}$ result: $\gamma = (68.7^{+5.2}_{-5.1})^o$(uncertainty~1° from BESIII input) *JHEP* ***02*** *(2021) 169*

$$r_B \exp[i(\delta_B \pm \gamma)] = x_\pm + iy_\pm$$

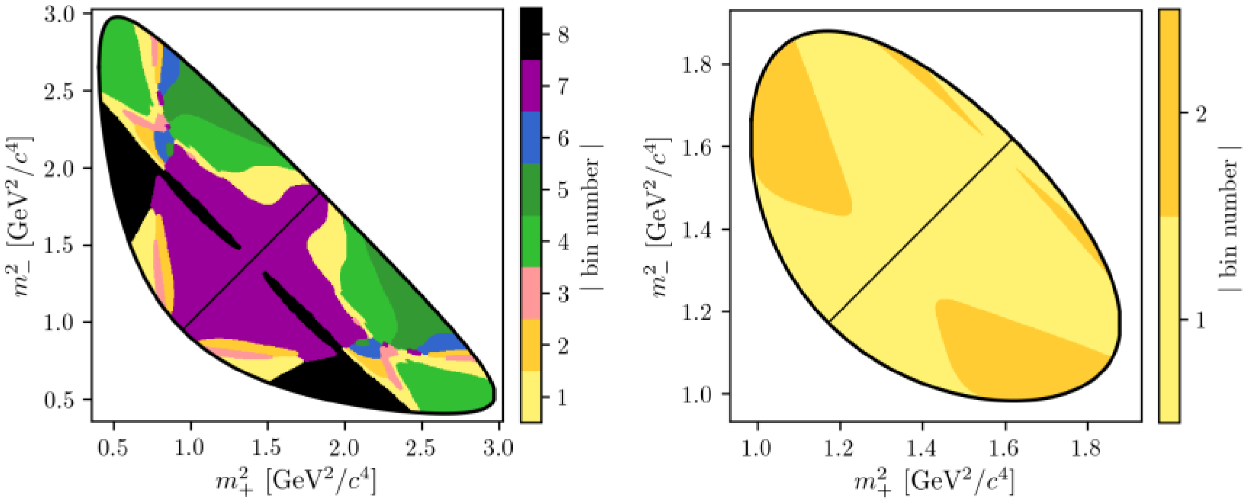
$$N^-_{\mp i} \propto F_{\pm i} + (x^2_- + y^2_-)F_{\mp i} + 2\sqrt{F_i F_{-i}}(x_\pm c_{\pm i} \mp y_\pm s_{\pm i})$$

F_i : Fractional yield of flavour tagged D^0 into bin i

Measured in control channel: $\bar{B}^0 \to D^{*+}\mu^-\nu_\mu X$

c_i/s_i : Strong phase difference of $D^0 - \bar{D}^0$ decays

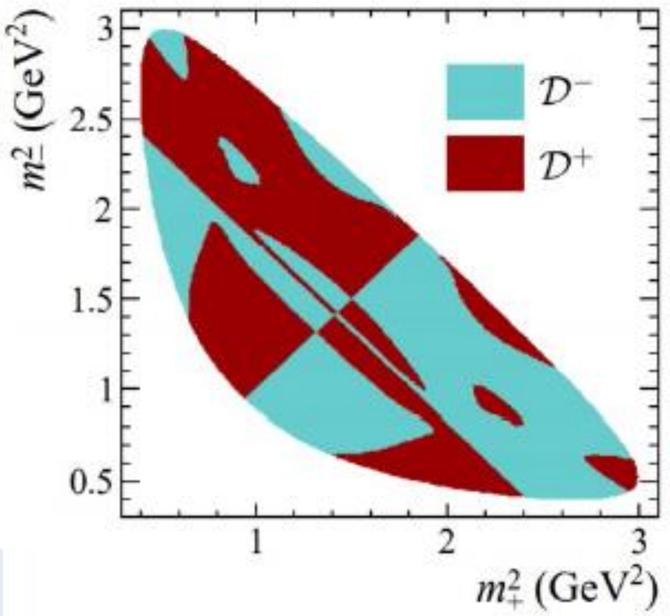
External input from BESIII and CLEO-c



[1] A. Giri, Y. Grossman, A. Soffer and J. Zupan, Phys. Rev. D 68 (2003) 054018

Unbinned model-independent method

- Basic idea: Bins → Events (*EPJC, 2018, 78(2)*)
  - Make most use of amplitude info in phase space
- Fourier expansion the amplitude by strong phase
  - Parameters definition similar to BPGGSZ method



- $\bar{a}_n^{B\pm} = \bar{h}_B\{a_n^{D\mp} + r_B^2 a_n^{D\pm} + 2[x_+ a_n^C \pm y_+ a_n^S]\}$
- $\bar{b}_n^{B\pm} = \bar{h}_B\{-b_n^{D\mp} + r_B^2 b_n^{D\pm} \pm 2[x_+ b_n^C - y_+ a_n^S]\}$
- $a_n^{B\pm} = h_B\{a_n^{D\pm} + r_B^2 a_n^{D\mp} + 2[x_- a_n^C \mp y_- a_n^S]\}$
- $b_n^{B\pm} = h_B\{b_n^{D\pm} - r_B^2 b_n^{D\mp} \pm 2[x_- b_n^C + y_- b_n^S]\}$

- $x_\pm = r_B \cos(\delta_B \pm \gamma)$
- $y_\pm = r_B \sin(\delta_B \pm \gamma)$

B sector

- $a_n'^{D\pm} = h_{D_f}\{a_n^{D\pm} + r_D^2 a_n^{D\mp} - 2R_D r_D[\cos(\delta_D) a_n^C \pm \sin(\delta_D)\, a_n^S]\}$
- $a_n^{CP\pm} = h_{CP}[a_n^{D\pm} + a_n^{D\mp} - 2\lambda_{CP} a_n^C]$
- $a_{mn}^{DD\pm\pm} = h_{DD}[a_m^{D\pm} a_n^{D\mp} + a_m^{D\mp} a_n^{D\pm} - 2(a_m^C a_n^C \pm a_n^S a_m^S)]$

- $\lambda_{CP} = 2F_+ - 1$

D sector

LHCb&BESIII joint analysis comes out soon

Time dependent measurement

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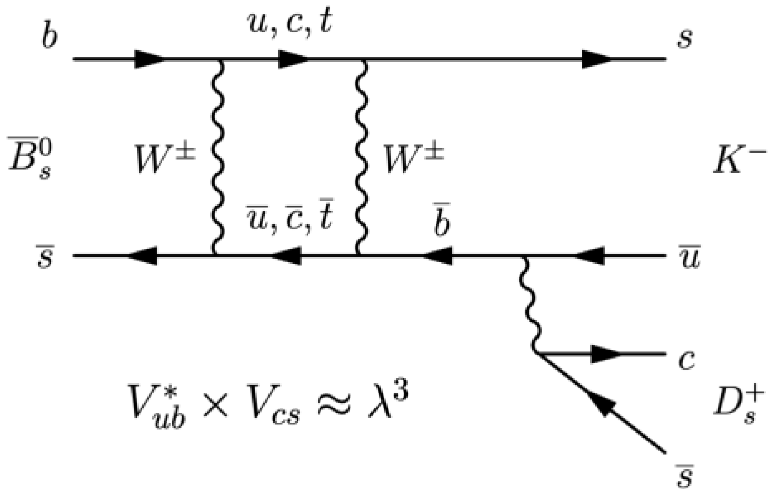
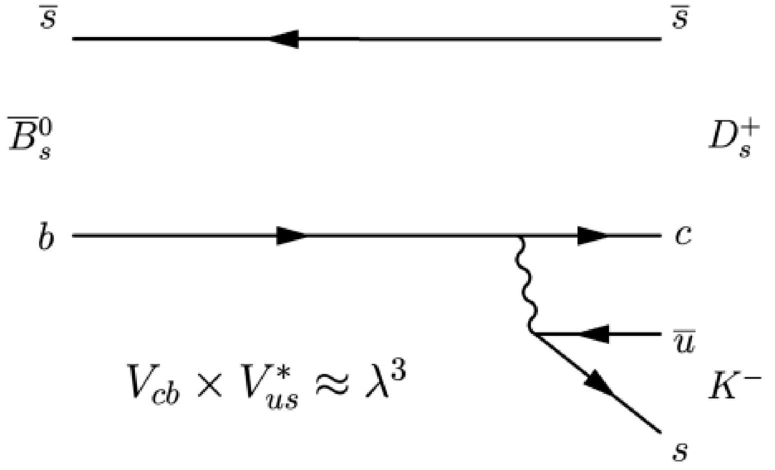
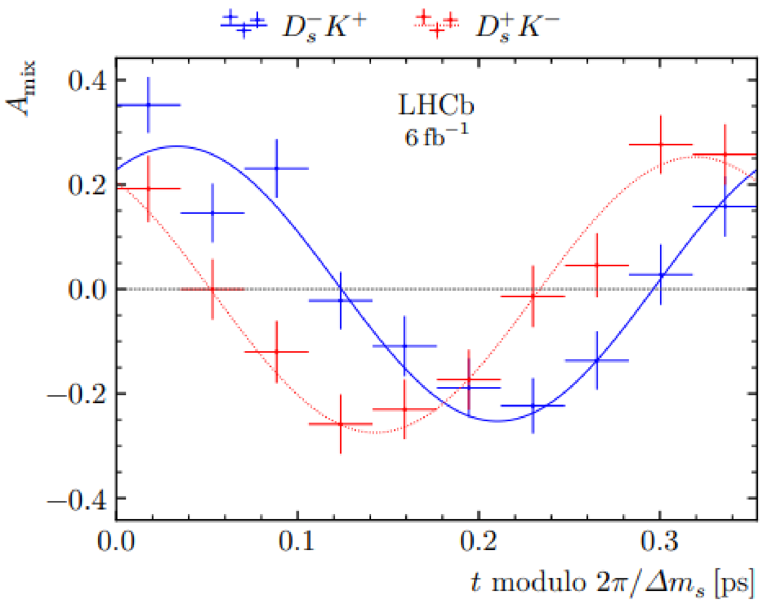
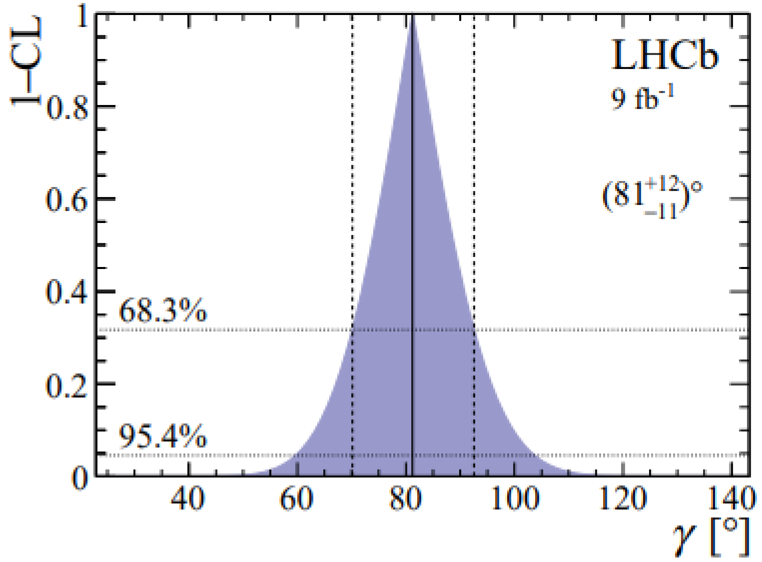
- Golden decays: $B_S \rightarrow D_S K$
  - larger interference: $r_B^{D_S K} \sim 0.4$ ($r_B^{DK^+} \sim 0.1$)
  - Use flavor tagging to determine the initial flavor
  - Interference between mixing and decay amplitudes gives sensitivity to **$\gamma+(-)2\beta_{(s)}$**





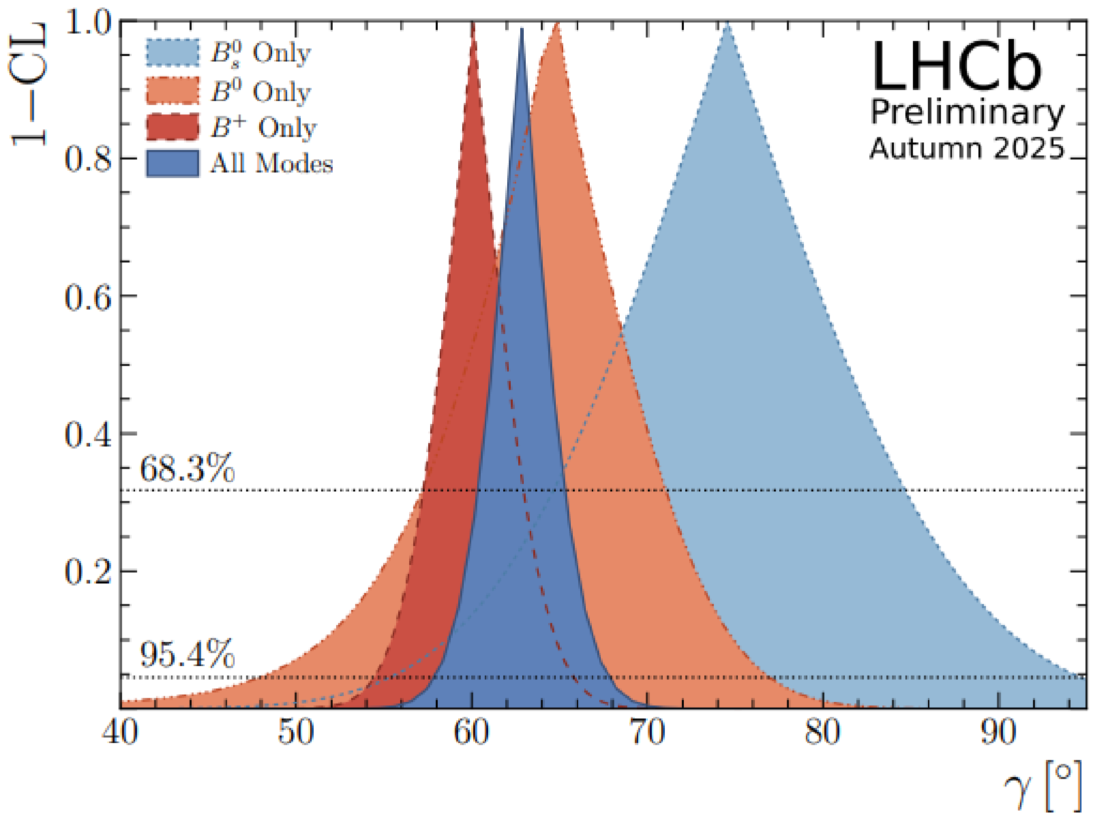




LHCb γ combination

LHCb-CONF-2025-003

- Best knowledge of γ comes from combination of many measurements
- 20 LHCb B decay measurements + 12 D decay measurements + 14 inputs from LHCb, HFLAV, BESIII and CLEO-c = 29 physics parameters of interest + additional nuisance parameters

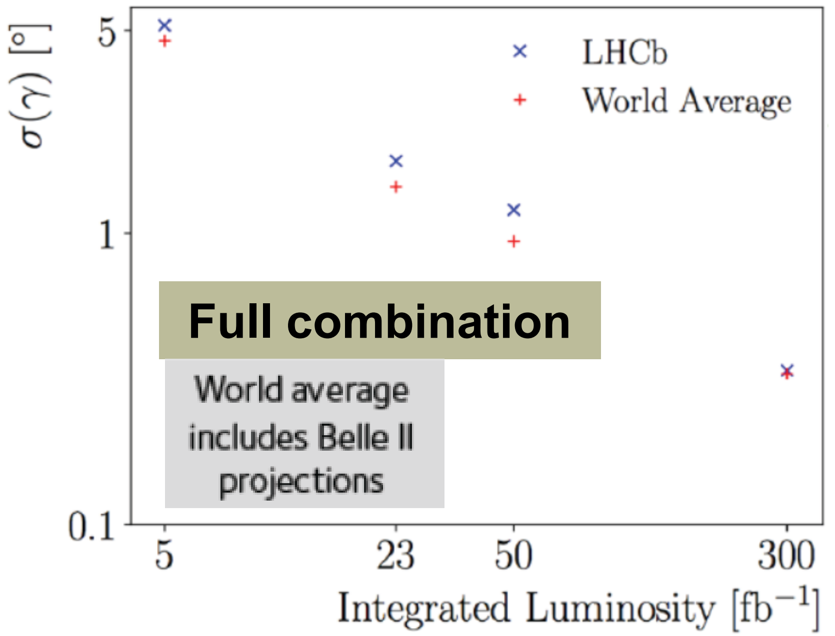


$$\gamma = (62.8 \pm 2.6)^o$$

surpass LHCb design: 4°

- Previous tension between B_s^0 and other modes smaller, B_s^0 modes still with largest uncertainty
- Sensitivity dominated by B^+ modes
- Charm inputs crucial for γ measurements

Future prospects for γ@ LHCb



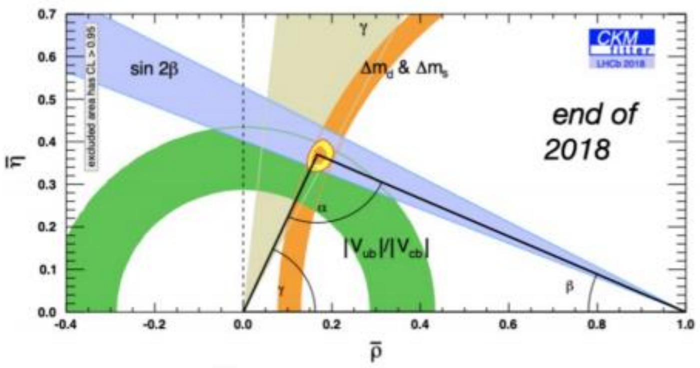
- Status now:
  - Error for γ is about 4°
  - BESIII contribute about 1°
- Around 2030
  - Less than 1° will be achieved
  - BESIII 20fb^{-1} data → improve the error to 0.4°
- (>)2035
  - LHCb upgradeII → sensitivity <0.4°
  - Need more charm factory data (STCF)

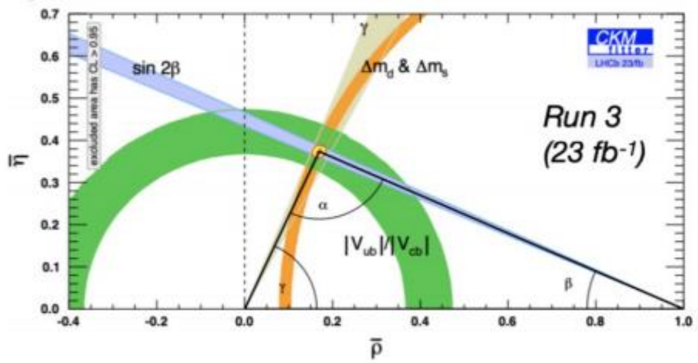
dataset	Int. Lum	Achieve year	γ precision
LHCb Run1 (7,8TeV)	3 fb^{-1}	2012	8°
LHCb Run2 (13TeV)	6 fb^{-1}	2018	4°
BelleII Run	50 ab^{-1}	20xx	1-2°
LHCb upgrade (14TeV)	50 fb^{-1}	2030	<1°
LHCb upgradeII (14TeV)	200 fb^{-1}	(>)2035	<0.4°

Summary

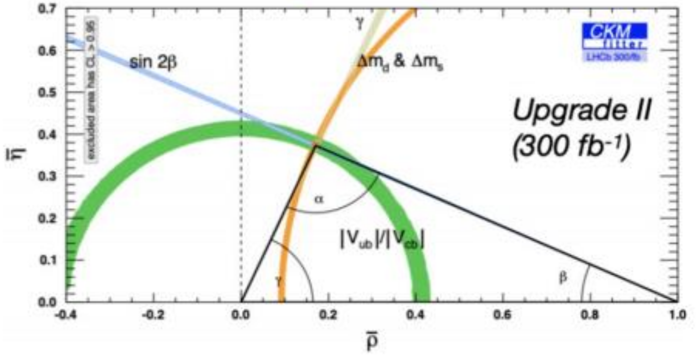
- The precision of the CKM elements and angles have greatly improved

LHCb-only inputs for UT





LHCb U2 + LQCD improvement



- LHCb play important role in measuring CKM elements and angle

- Already collected more data in Run 3 than in Run 1+2 combined, **Stay tuned !**

- Carry out an unprecedentedly rigorous test of the Standard Model in UpgradeII

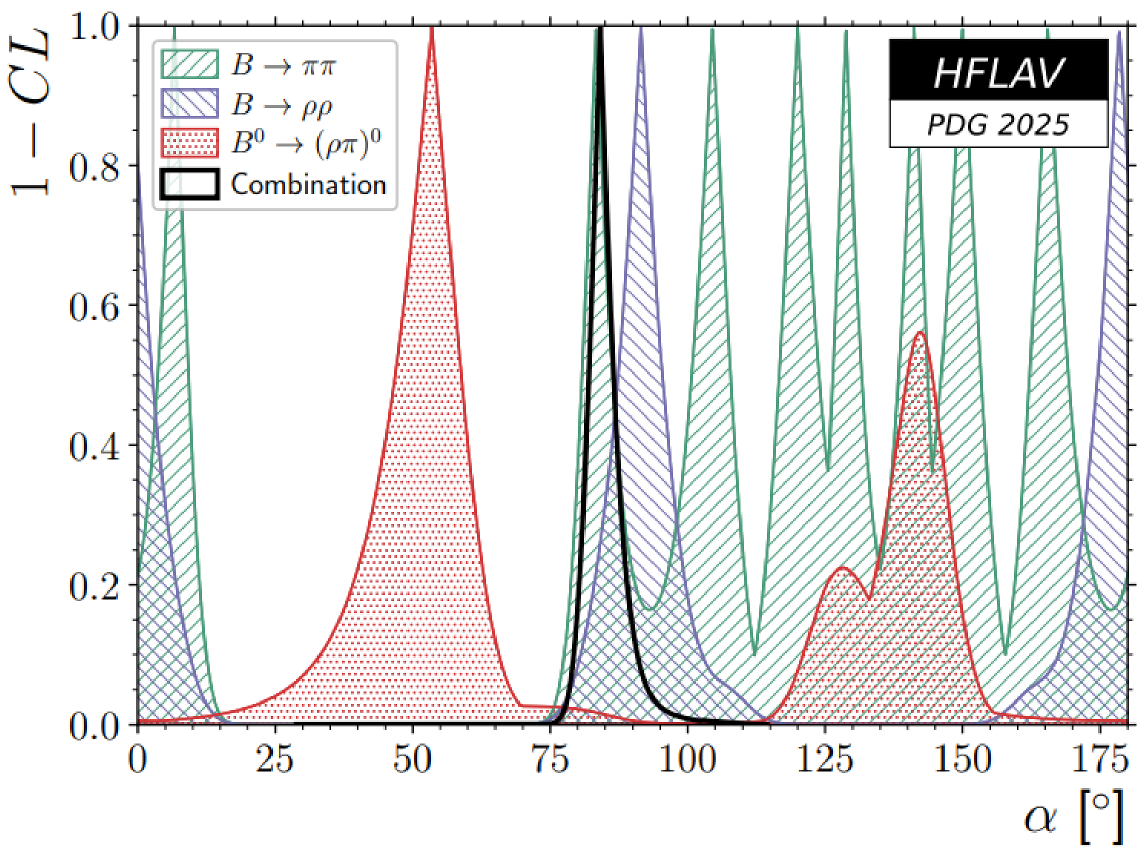
Thank you!

α status

- α is complex, isospin analysis by using:
  - $B_d^0 \to \rho^+\rho^-, \rho^0\rho^0, B_u^+ \to \rho^+\rho^0$

- Time-dependent CP Asymmetries

- LHCb can contribute in many modes



$$\begin{aligned}\phi_s^{SM}(B_s^0 \to \phi\phi) &= -\arg(\eta_f \lambda_f) = -\arg\left(\eta_f \frac{q}{p}\frac{\bar{A}_f}{A_f}\right) = \Phi_M^{SM} - \Phi_D^{SM} \\ &\approx 2\ \arg(V_{ts}^* V_{tb}) - \arg(V_{tb} V_{ts}^* / V_{tb}^* V_{ts}) = -2\chi + 2\chi = 0\,.\end{aligned}$$

$$\begin{aligned}\phi_s(B_s^0 \to \phi\phi) &\equiv \phi_s^{SM}(B_s^0 \to \phi\phi) + \Phi_M^{NP}(B_s^0) - \Phi_D^{NP}(B_s^0 \to \phi\phi) \\ &= \phi_s^{SM}(B_s^0 \to \phi\phi) + \phi_s^{NP}(B_s^0 \to \phi\phi) \approx \phi_s^{NP}(B_s^0 \to \phi\phi)\,.\end{aligned}$$