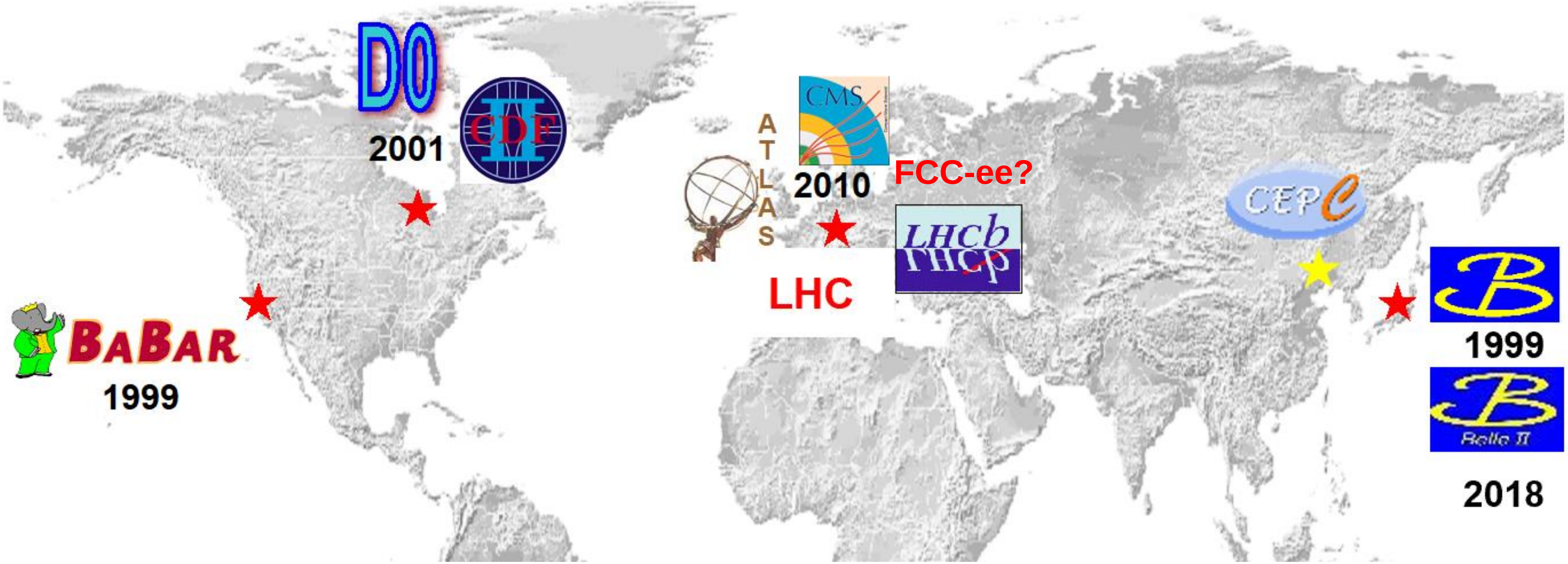


Overview of Beauty Physics Experiments

Yuehong Xie
Central China Normal University

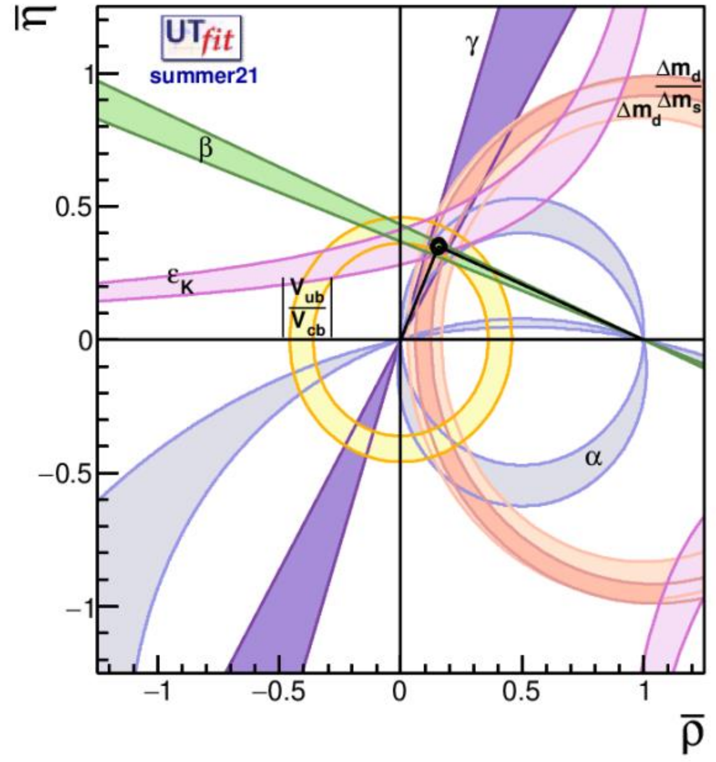
CEPC2022, 24-28 October 2022

Outline

- **Flavour physic and requirements on detector**
- **CP violation and CKM unitarity test**
- **Rare decays and LFUV**
- **Conclusions**

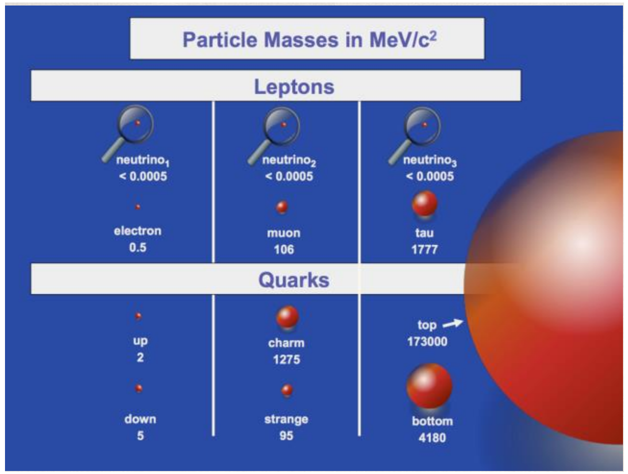
Disclaimer: many interesting studies on charm, QCD and hadron spectroscopy are not covered.

Flavour mysteries



- Yukawa couplings of Higgs to quarks ⇒ CKM matrix
  - The source of CP violation in the SM
  - Accommodating many experimental results with 4 parameters

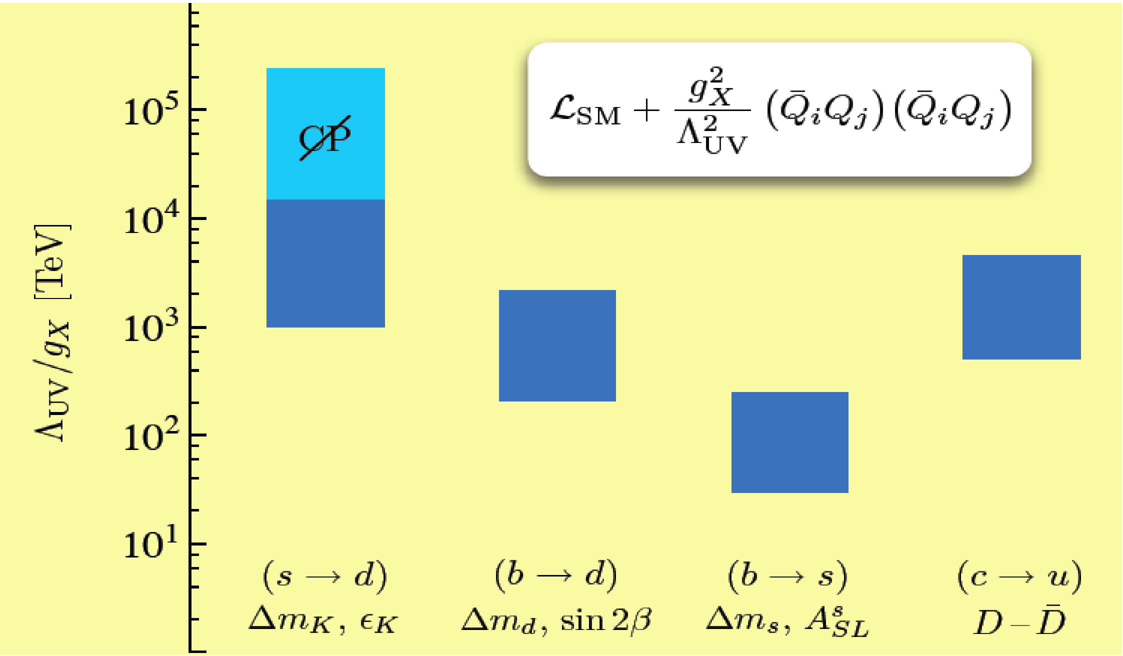
- Unexplained
  - Dynamic origin of hierarchies in quark masses & mixing
  - Matter-antimatter asymmetry of the universe



$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Flavour as a window to new physics

- **Unique strength of indirect searches**
  - Exploring NP scale far above TeV
  - Probing phase of NP couplings
  - Distinguishing NP scenarios



Generic bounds on New Physics scale (for $g_X \sim 1$)

- **A rich source of information**

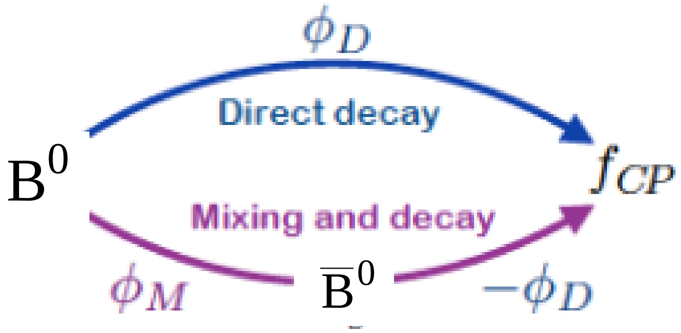
Interesting processes

- Tree processes: SM benchmarks
- Loop processes: sensitive to NP
- Forbidden processes: only seen in NP

Key observables

- Decay rates and ratios
- CP asymmetries
- Angular or time-dependent coefficients
- Lifetimes, polarizations, …

Top priority: CPV in neutral B decays



$$\lambda_{f_{CP}} = \eta_{f_{CP}} \frac{q}{p} \cdot \frac{\bar{A}_{\bar{f}_{CP}}}{A_{f_{CP}}}$$

← amplitude ratio

CP eigenvalue ($\eta_{f_{CP}}$)

$\frac{q}{p} \approx e^{-2i\beta}$

❑ Time-dependent CP asymmetry

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

$$\propto S\sin(\Delta m_d t) - C\cos(\Delta m_d t)$$

$$C = \frac{1 - |\lambda_{f_{CP}}|^2}{1 + |\lambda_{f_{CP}}|^2}$$

$$S = \frac{2\,\mathrm{Im}\,\lambda_{f_{CP}}}{1 + |\lambda_{f_{CP}}|^2}$$

❑ Need to determine

- **Initial flavor of the *B* meson: kaon and lepton PID essential**
- **Decay time of the *B* meson: vertex reconstruction essential**

Requirements on detector

- Ability to find signals and suppress background
  - Good momentum and mass resolution
  - Excellent particle identification
  - Flexible and efficient trigger (for hadron colliders)

- Ability to identify the initial B flavor
  - Excellent particle identification for $e^{\pm}, \mu^{\pm}, K^{\pm}$

- Precise measurement of proper decay time
  - Excellent vertex resolution

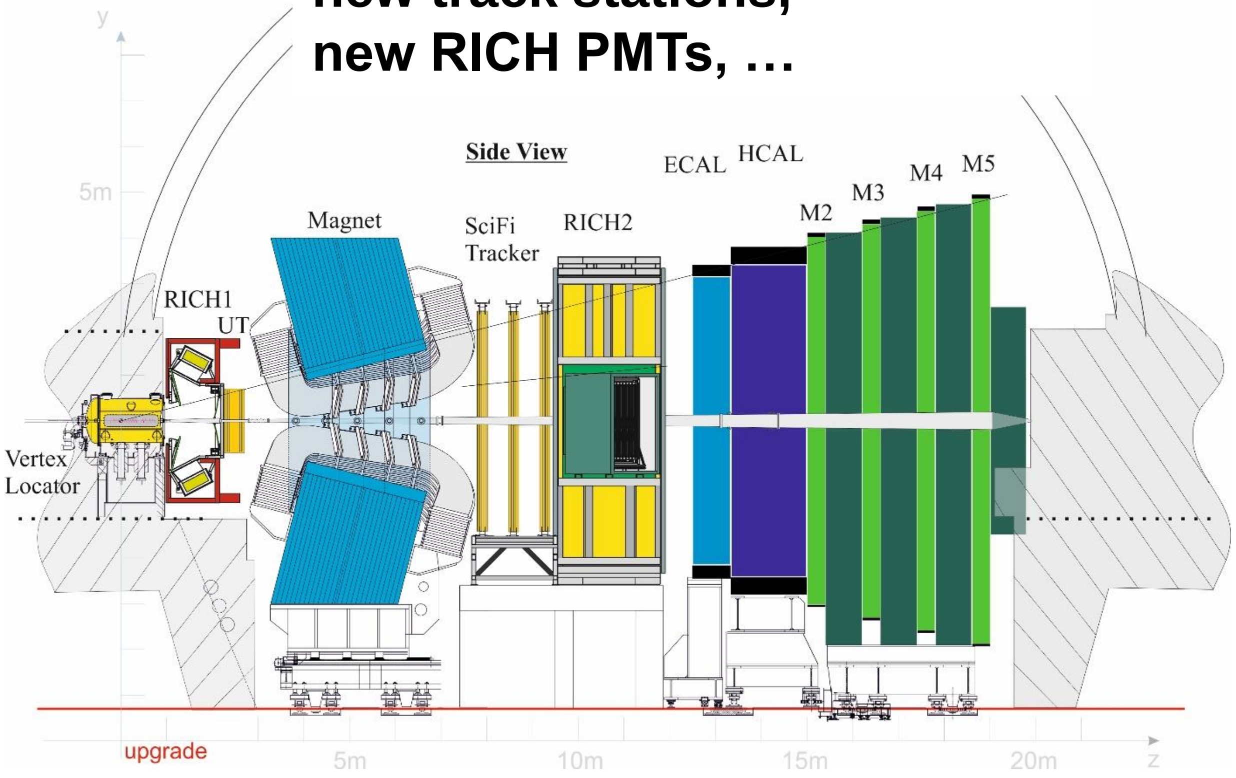
⇒ Very demanding on the capacity of

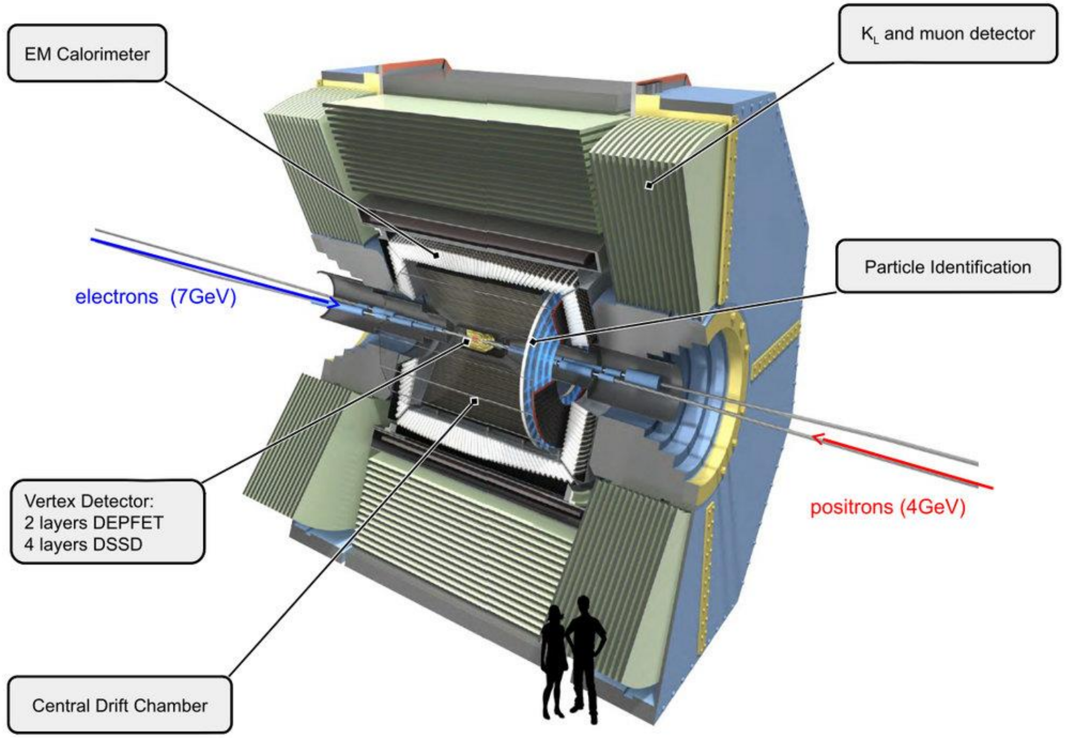
track & vertex reconstruction,
hadron & lepton identification

Typical B physics detectors

Upgrade I

new pixel VELO,
new track stations,
new RICH PMTs, …





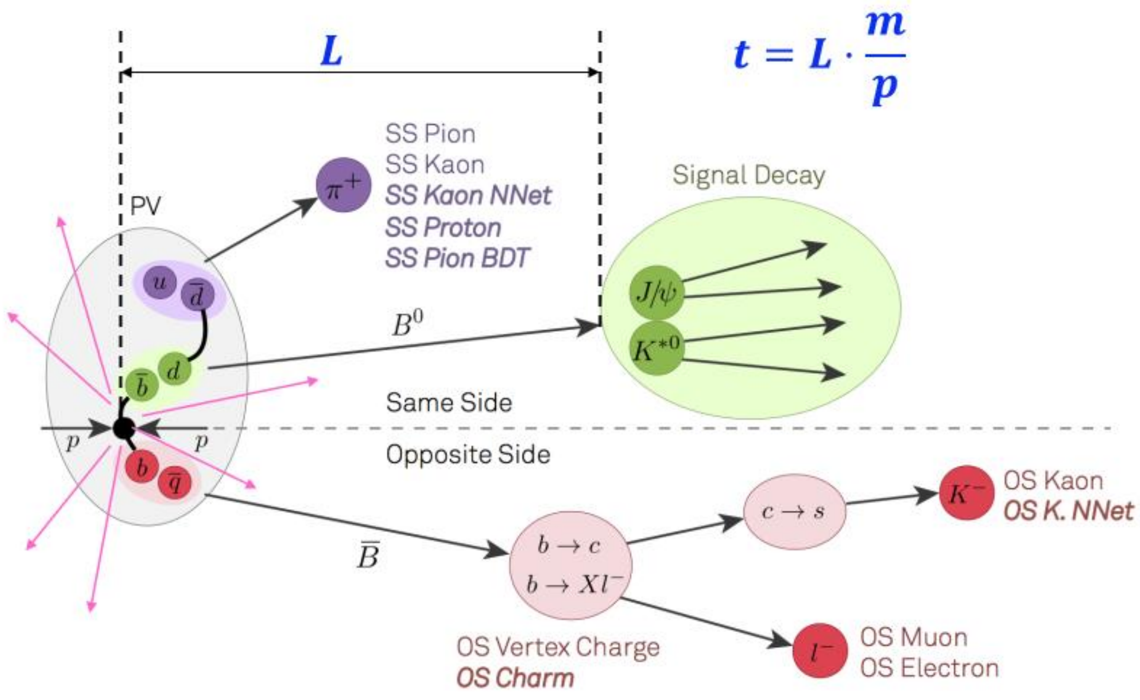
Produces ~ $\text{few} \times 10^{12}$ $B\bar{B}$ per year (Run III)

Produces 10^{10} $B\bar{B}$ per year at $\Upsilon(4S)$

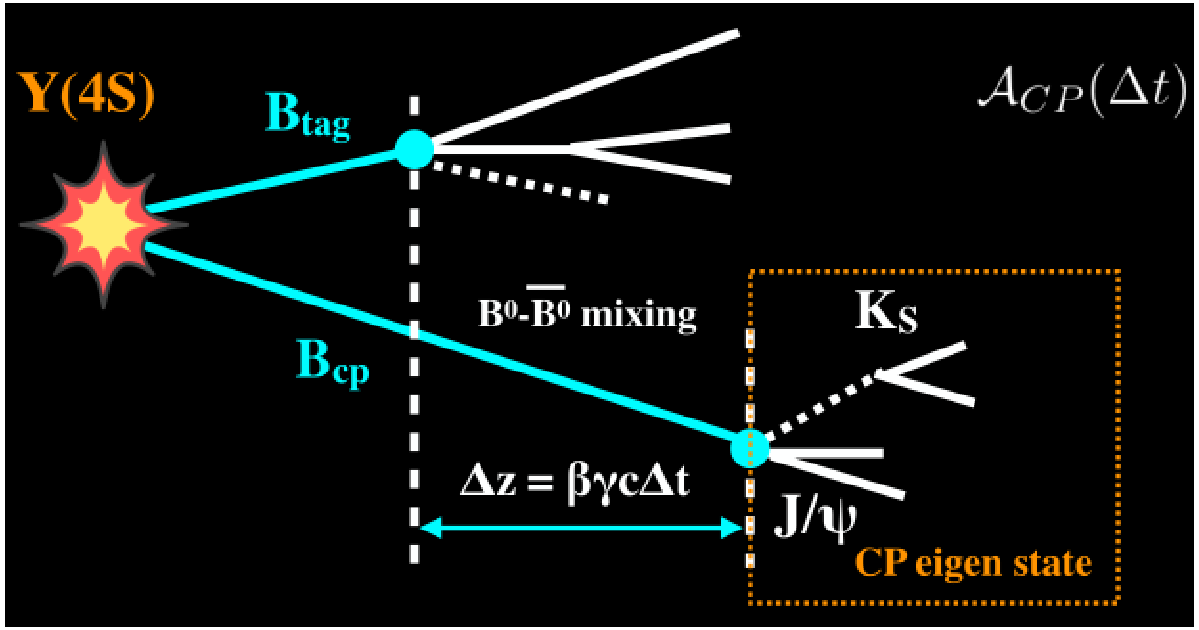
Both use silicon technology for vertexing and RICH for hadron PID!

Flavour tagging & time reconstruction

LHCb



Belle II

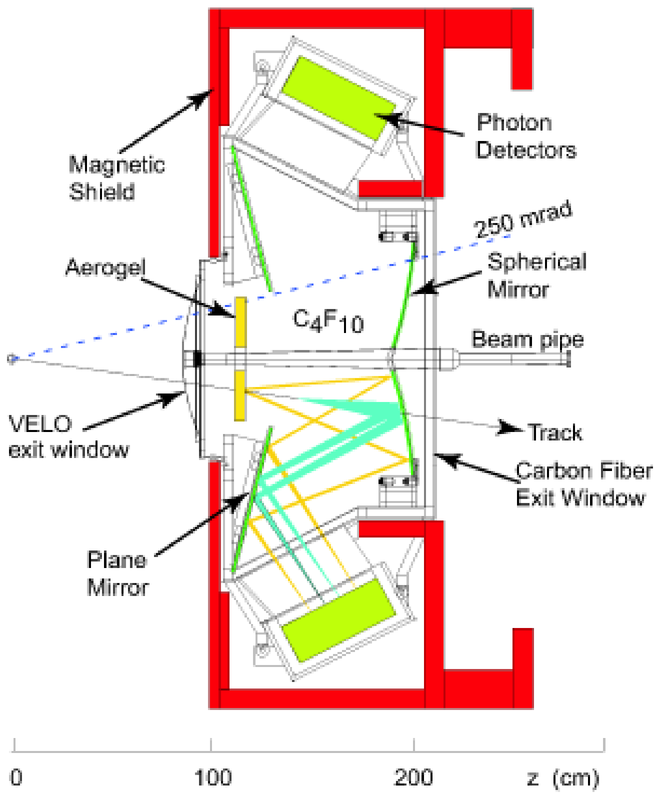


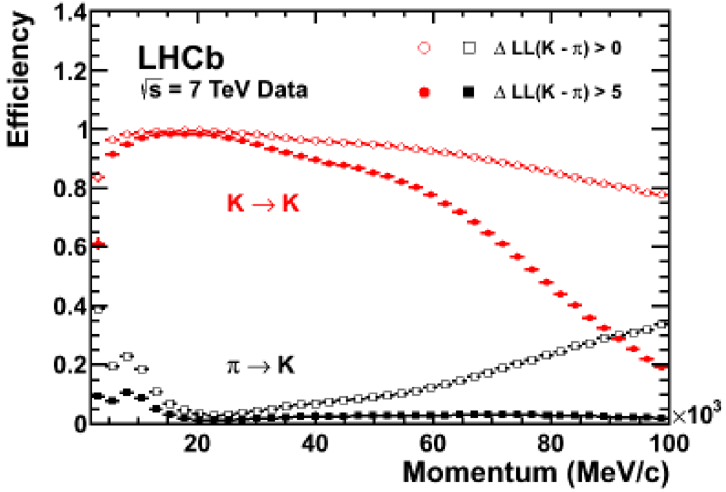
Tagging power $\epsilon(1-2\omega)^2 \sim 4-5\%$
Time resolution $\sim 40-50$ fs
（c.f. B_s^0 oscillation period ~ 350 fs）

Tagging power $\epsilon(1-2\omega)^2 \sim 35\%$
Time resolution ~ 150 fs

Magic LHCb RICHs

Two Ring Imaging Cherenkov detectors



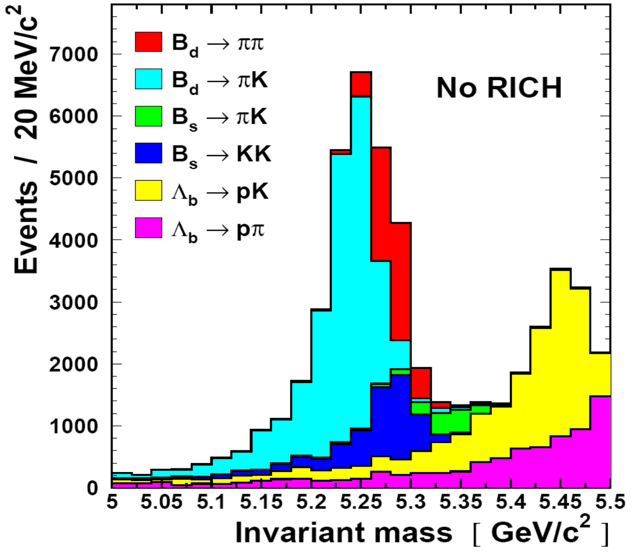


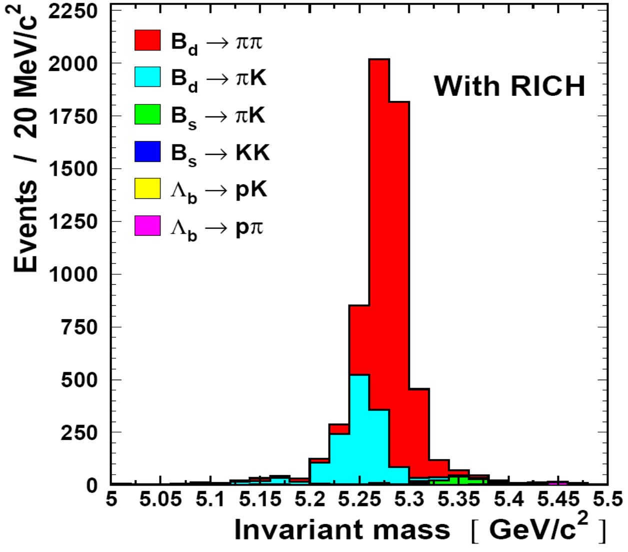
Good K/π separation up to 100 GeV

$\epsilon(K \to K) \sim 95\%$

$\epsilon(\pi \to K) \sim 5\%$

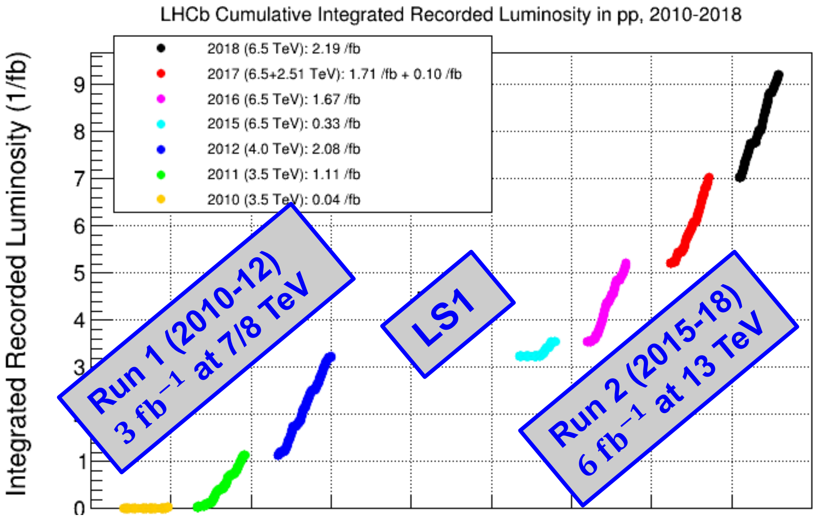
Signal: $B^0 \to \pi^+\pi^-$; Background: $B^0 \to K^-\pi^+, B_s^0 \to K^+\pi^-$



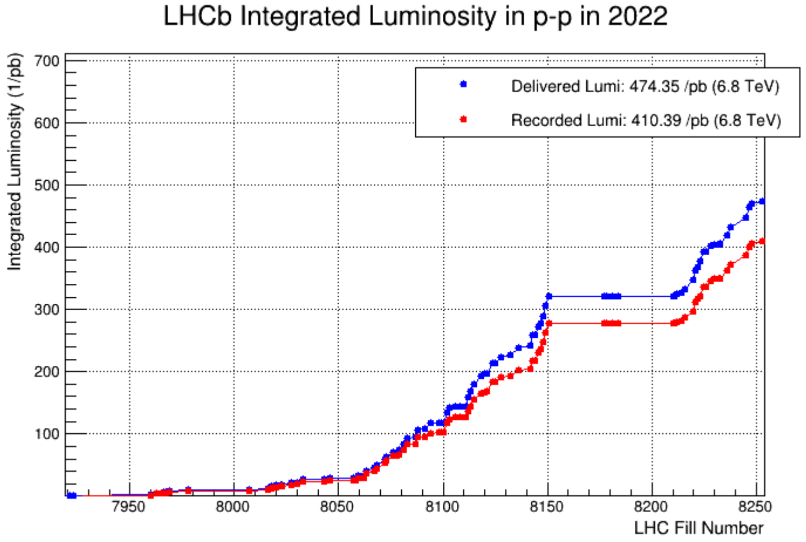


LHCb status

Data taking Run 1&2

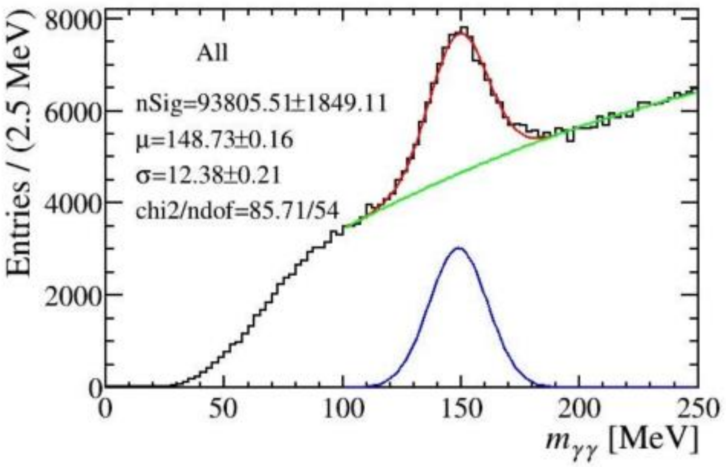


Data taking in 2022

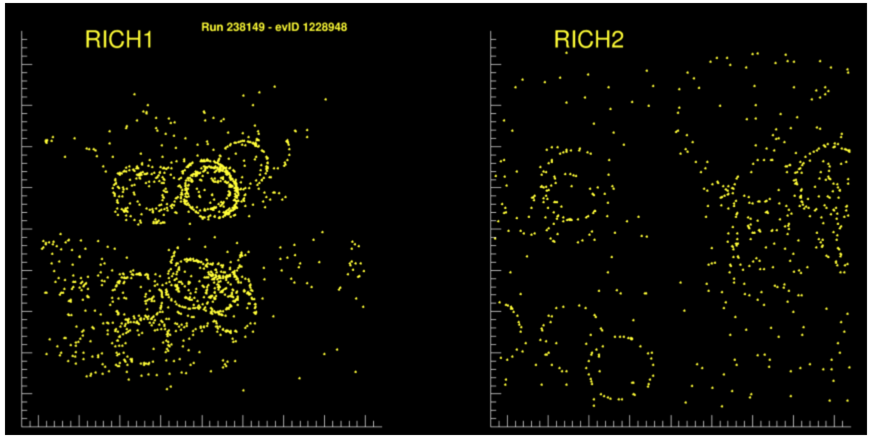


05/07: First collision
23/08: LHC incident
24/09: Restart
21/10: VELO closing
27/11: End of run
March 2023: Restart

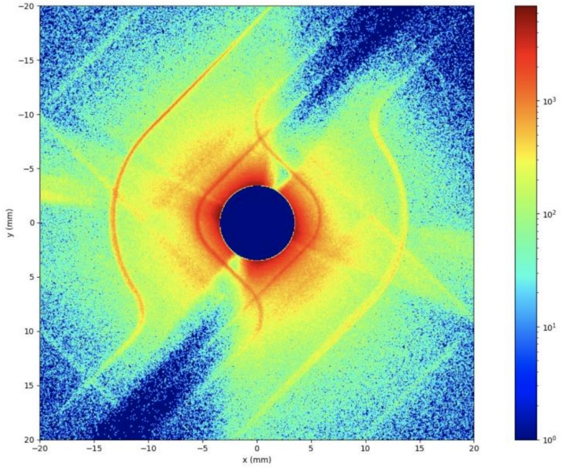
π^0 peaks



Rings in RICHs

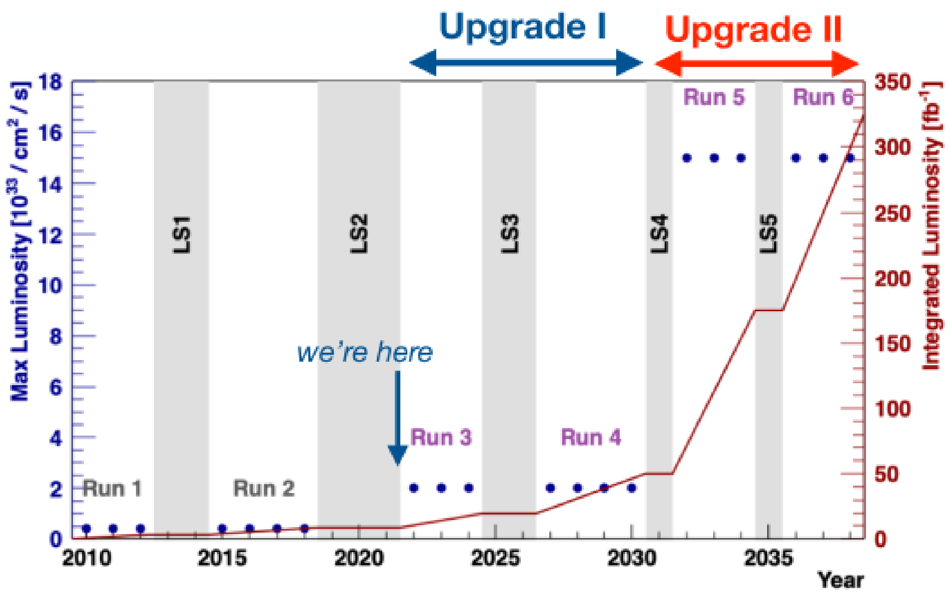


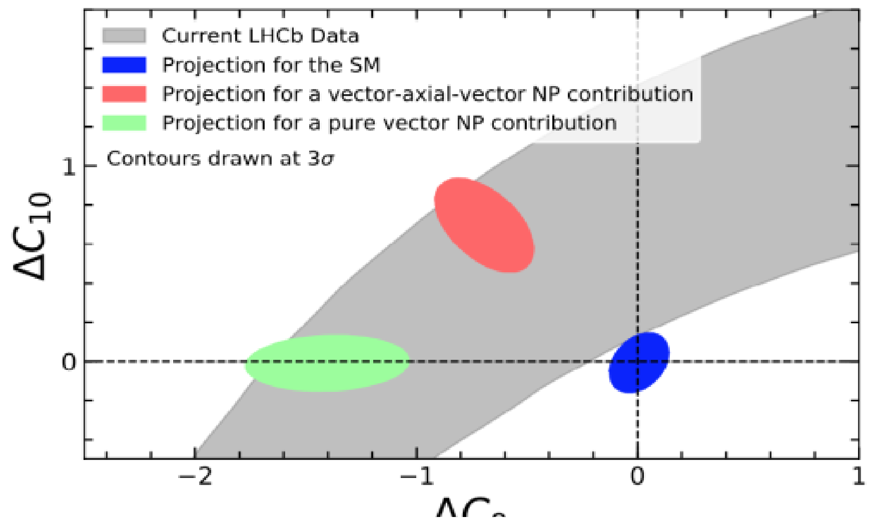
Closed VELO

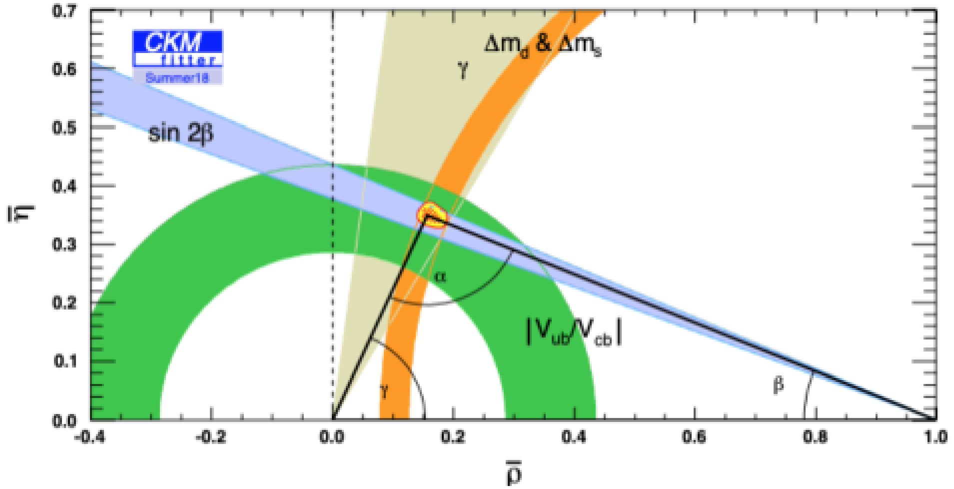


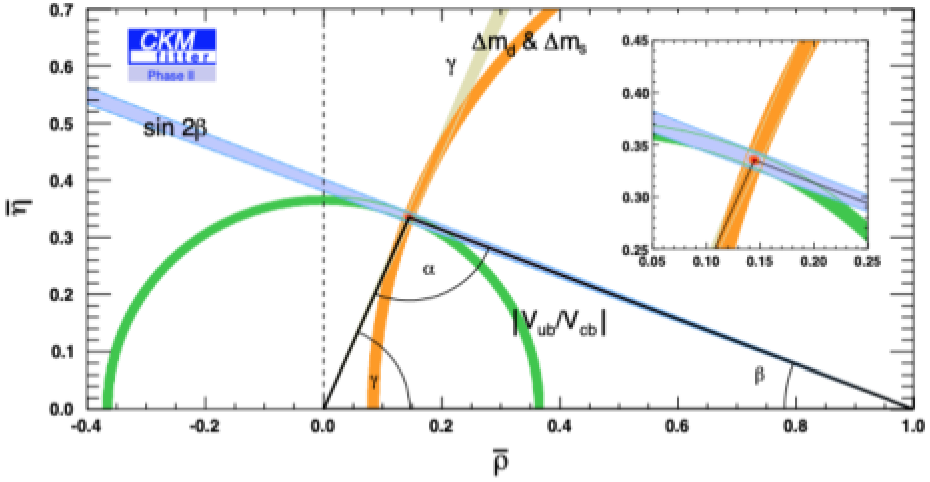
LHCb long term plan

- Accumulate 25 fb^{-1} after Run 3, 50 fb^{-1} after Run 4, 300 fb^{-1} after Upgrade II
- Measure CKM parameters and study rare decays with unprecedented precision



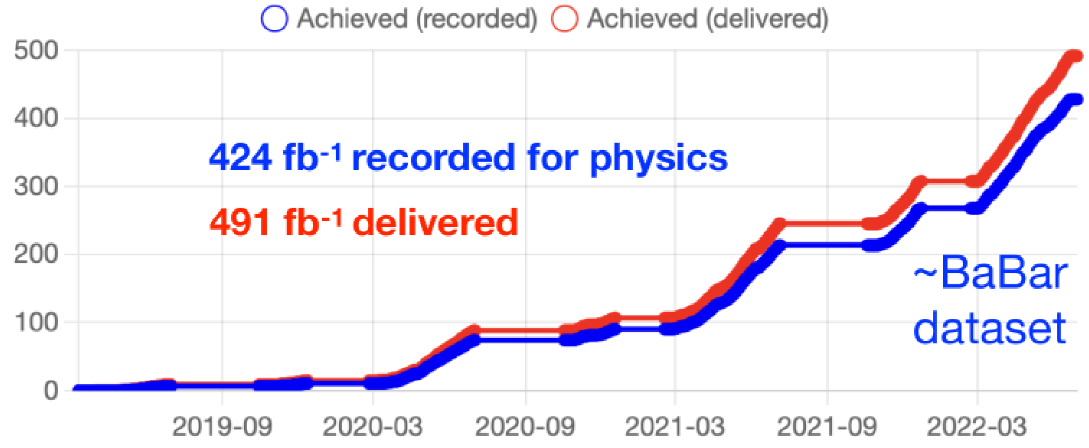






BELLE II status and plan

Data taking 2019-2022

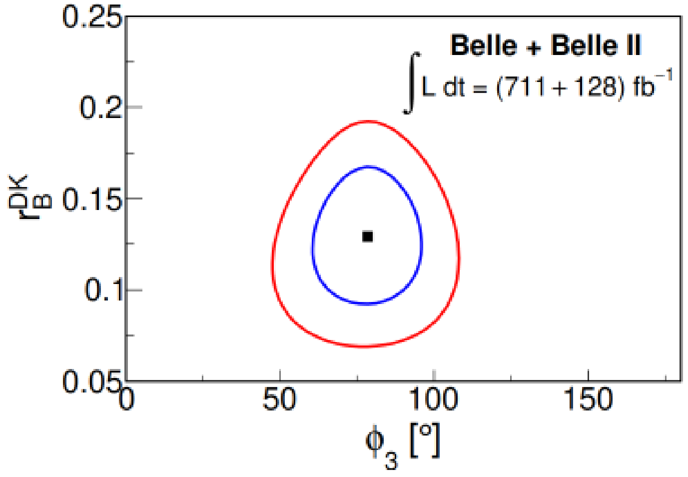


- **Interesting results with 0.5 ab^{-1} recorded**
  - Charm lifetime measurements
  - $\gamma(\phi_3)$ measurement with $B^+ \to D(K_S^0 hh)h^+$
  - Search for $B^+ \to K^+\nu\bar{\nu}$
  - Time-dependent CPV measurements in $B^0 \to J/\psi K_S^0$, $\pi\pi$, $\rho\rho$, $K_S^0 K_S^0\ K_S^0$
- **Expect 5 (50) ab^{-1} before (after) upgrade**

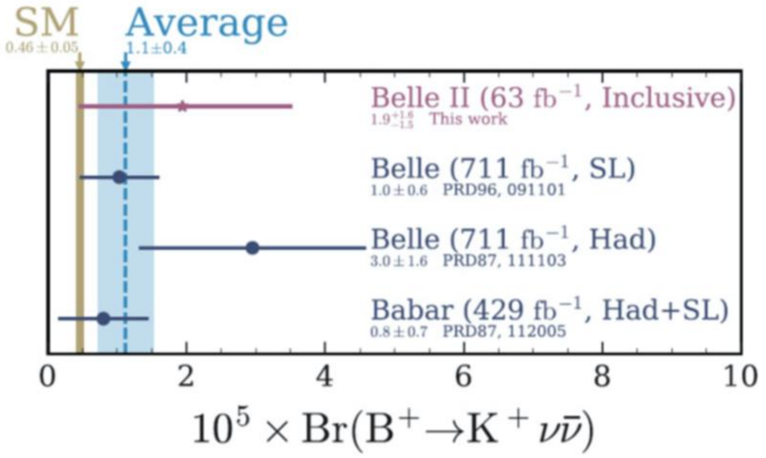
$$\begin{cases} \tau(D^0) = (410.5 \pm 2)\mathrm{fs} \\ \tau(D^+) = (1030.4 \pm 5.6)\mathrm{fs} \\ \tau(\Lambda_c^+) = (203.2 \pm 1.1)\mathrm{fs} \end{cases}$$

World best meas. achieved thanks to new PXD layers.

Phys. Rev. Lett. 127 (2021)



JHEP02 (2022) 063



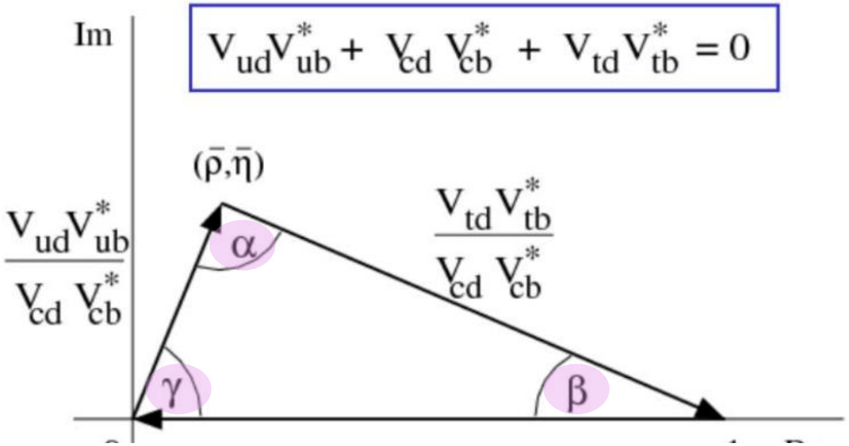
Phys. Rev. Lett. 27 (2021) 181802

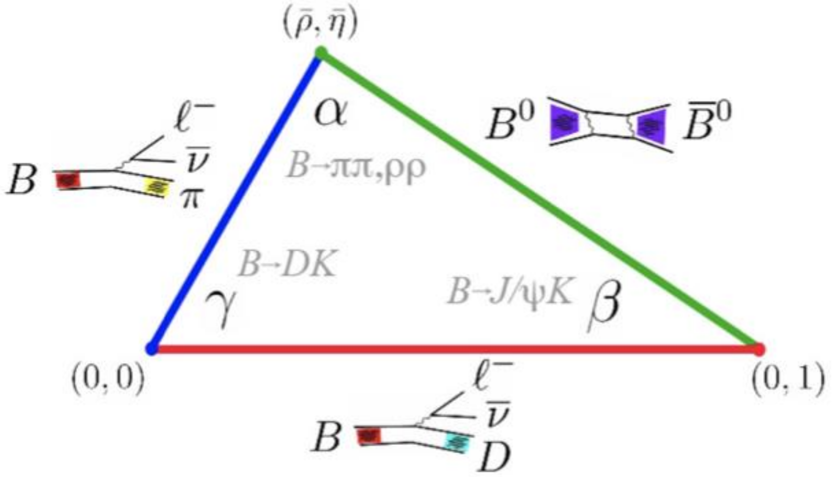
CP violation and CKM unitarity test

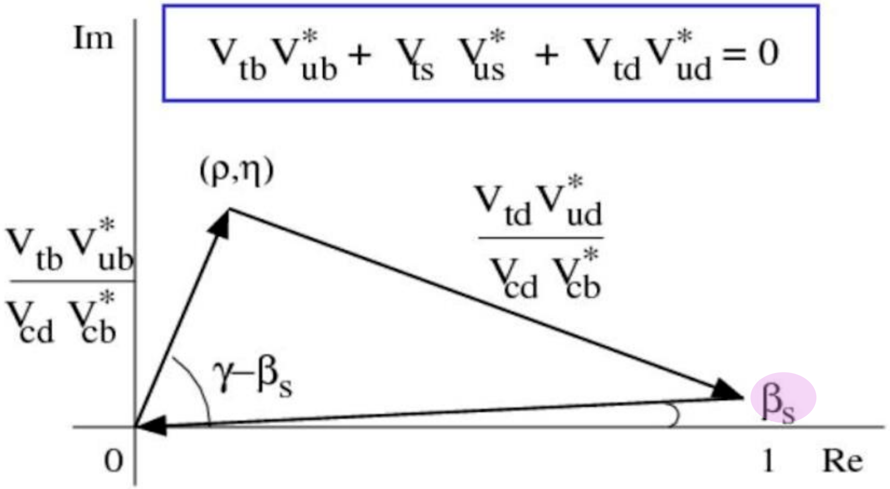
Test unitarity of the CKM matrix

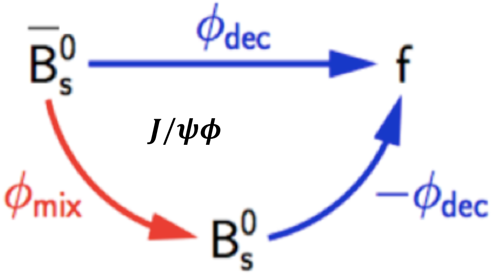
Measure triangle sides (rates, mixing) and angles (CP asymmetries) to test unitarity

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



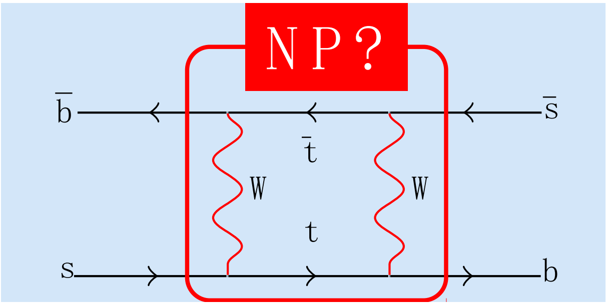






B meson mixing

$B_q^0 - \bar{B}_q^0$ mixing

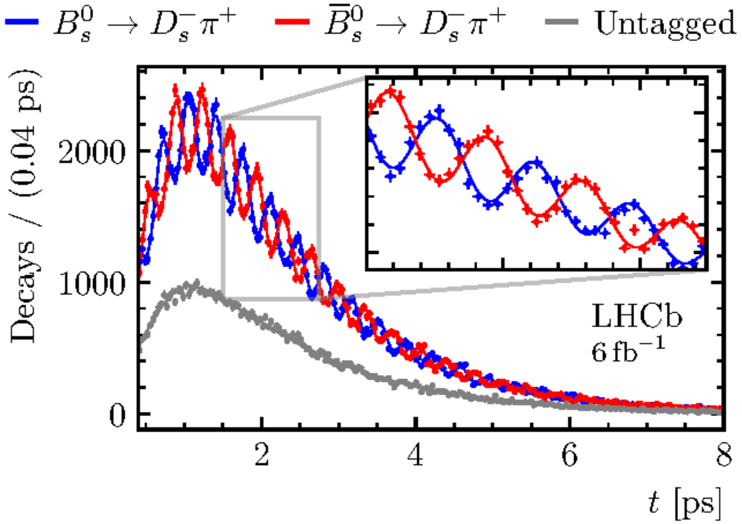


$$|B_L^q\rangle = p|B_q\rangle + q|\bar{B}_q\rangle$$

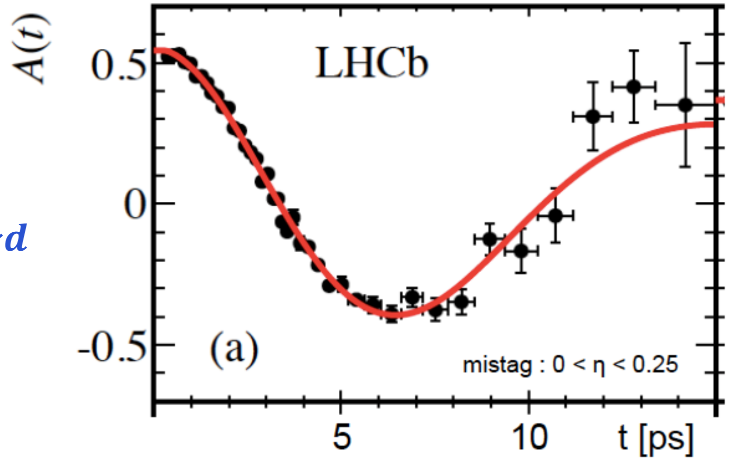
$$|B_H^q\rangle = p|B_q\rangle - q|\bar{B}_q\rangle$$

$$\Delta m_q = m_L - m_H$$

Δm_s



Δm_d



$$\Delta m_s = 17.7656 \pm 0.0057\ \mathrm{ps}^{-1}$$

$$\Delta m_d = 0.5050 \pm 0.0021 \pm 0.0010\ \mathrm{ps}^{-1}$$

LHCb Run 1, Nature Physics 18 (2022) 1

SM: $\Delta m_s = 18.4^{+0.7}_{-1.2}\ \mathrm{ps}^{-1}$

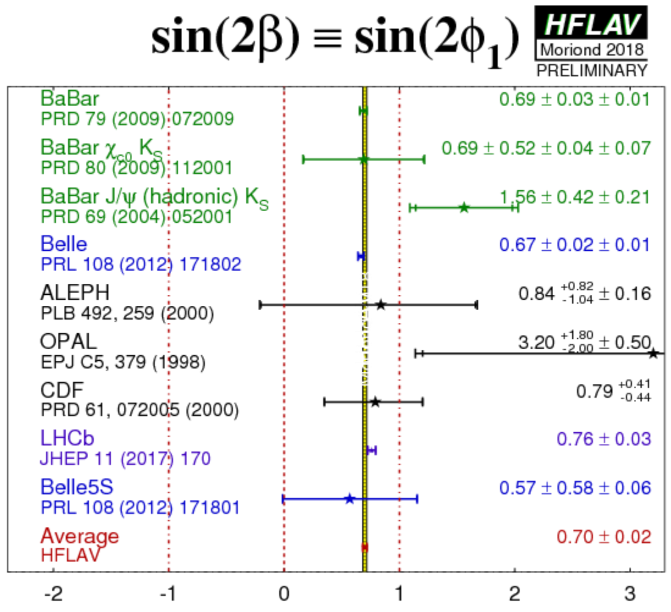
LHCb Run 1, EPJC 76 (2016) 412

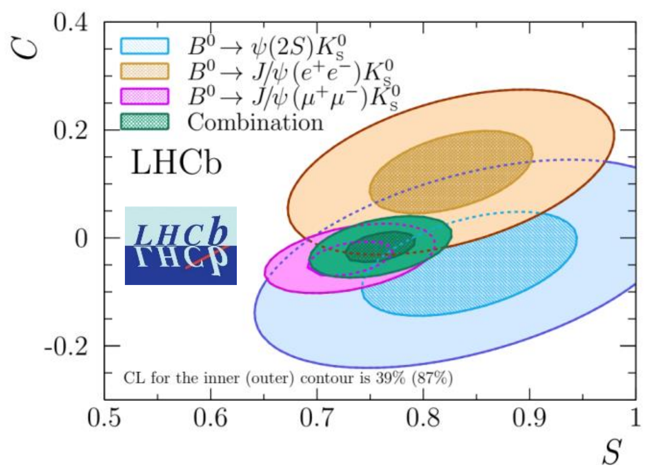
SM: $\Delta m_s = 0.533^{+0.022}_{-0.036}\ \mathrm{ps}^{-1}$ Luzio et al., JHEP 12 (2019) 009

CPV in B^0 decays: $\phi_d = 2\beta$

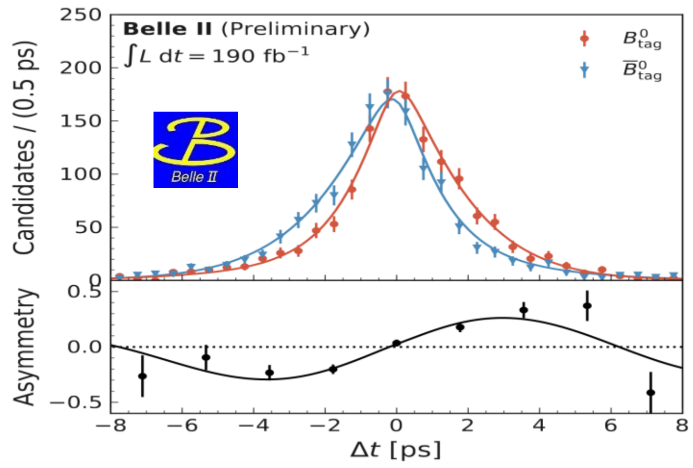
Time dependent CP violation: $A_{CP}(t) \propto C\cos(\Delta m_q t) + S\sin(\Delta m_q t)$

b → $c\bar{c}s$ processes are studied with increasing precision





LHCb, JHEP 11 (2017) 170



BELLE2-TALK-CONF-2022-080

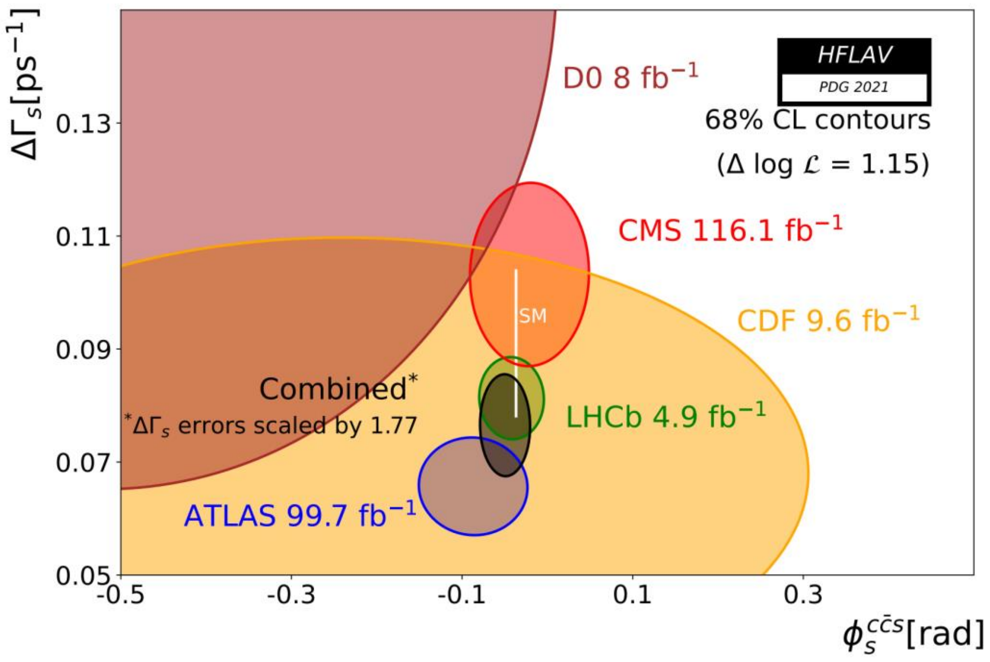
WA: $\sin 2\beta = 0.70 \pm 0.02$
SM: $\sin 2\beta = 0.731^{+0.029}_{-0.016}$

LHCb combined
$\sin 2\beta = 0.731 \pm 0.035 \pm 0.020$

BELLE II
$\sin 2\beta = 0.720 \pm 0.062 \pm 0.016$

CP violation in B_s^0: $\phi_s = -2\beta_s$

Huge efforts to measure ϕ_s



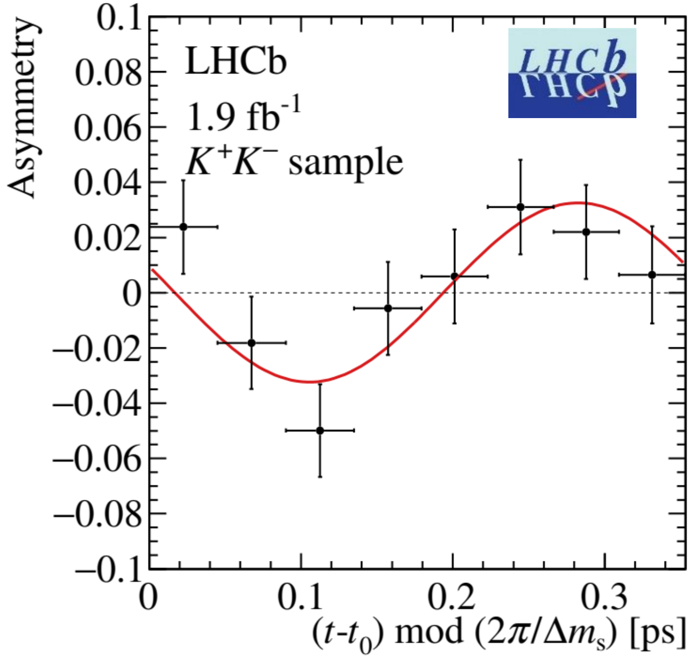
W.A.: $\phi_s = -0.050 \pm 0.019$ rad

Indirect: $\phi_s = -0.037 \pm 0.001$ rad

Experimental uncertainty much larger than that of the indirect value from CKM fit.

Tension between experiments in lifetimes.

Observation of time-dependent CP violation in $B_s^0 \to K^+K^-$



$S_{KK} = 0.123 \pm 0.034 \pm 0.015$

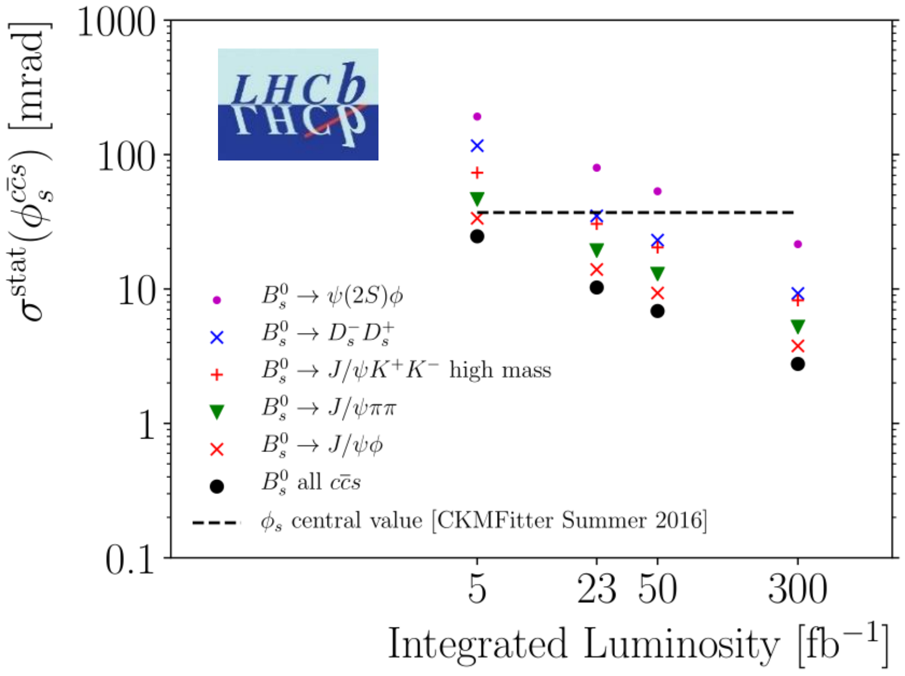
$C_{KK} = 0.164 \pm 0.034 \pm 0.014$

JHEP 03 (2021) 075

Can combine $B_s^0 \to K^+K^-$ & $B^0 \to \pi^+\pi^-$ to measure γ and $-2\beta_s$

PLB 739 (2015) 1

Prospects for ϕ_q in $b \to c\bar{c}s$



- **Precision projections**
  - LHCb with 50 (300) fb^{-1}
    - $\sigma(\phi_s) \sim 6\ (3)$ mrad
    - $\sigma(\sin 2\beta) \sim 0.006\ (0.003)$ LHCb, CERN-LHCC-2018-027
  - BELLE II with 5 (50) ab^{-1}
    - $\sigma(\sin 2\beta) \sim 0.012\ (0.005)$ BELLE II, arXiv:1011.0352

- **A deep understanding of the penguin pollution is necessary**

Possible strategy: SU(3) analysis of $b \to c\bar{c}s$ and $b \to c\bar{c}d$ modes

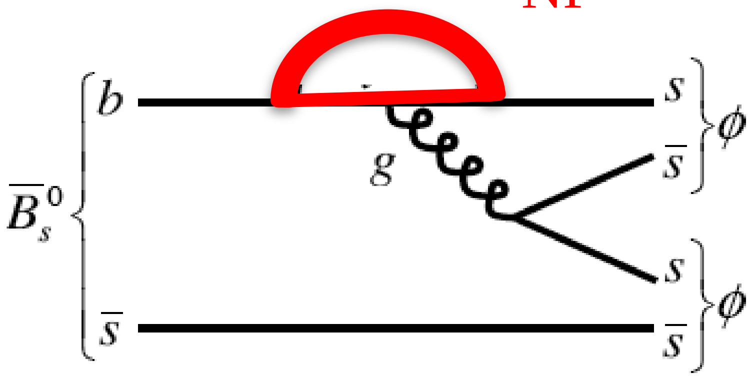
$B_s^0 \to J/\psi K_S^0$, $B^0 \to J/\psi\pi^0$, $B^+ \to J/\psi\pi^+$ for $B^0 \to J/\psi K_S^0$

$B^0 \to J/\psi\rho$, , $B_s^0 \to J/\psi\bar{K}^{*0}$, $B_s^0 \to J/\psi\bar{K}^{*0}$ for $B_s^0 \to J/\psi\phi$

} Global analysis, considering SU(3) symmetry breaking

Bruyn, Fleischer, JHEP 03 (2015) 145; LHCb, Phys. Lett. B 742 (2015) 38

$\phi_s^{q\bar{q}}$ in $b \to s$ decays



- **Partial run 2 results**

$B_s^0 \to \phi\phi$ JHEP 12 (2019) 155

$\phi_s^{s\bar{s}} = (-0.073 \pm 0.115 \pm 0.027)$ rad

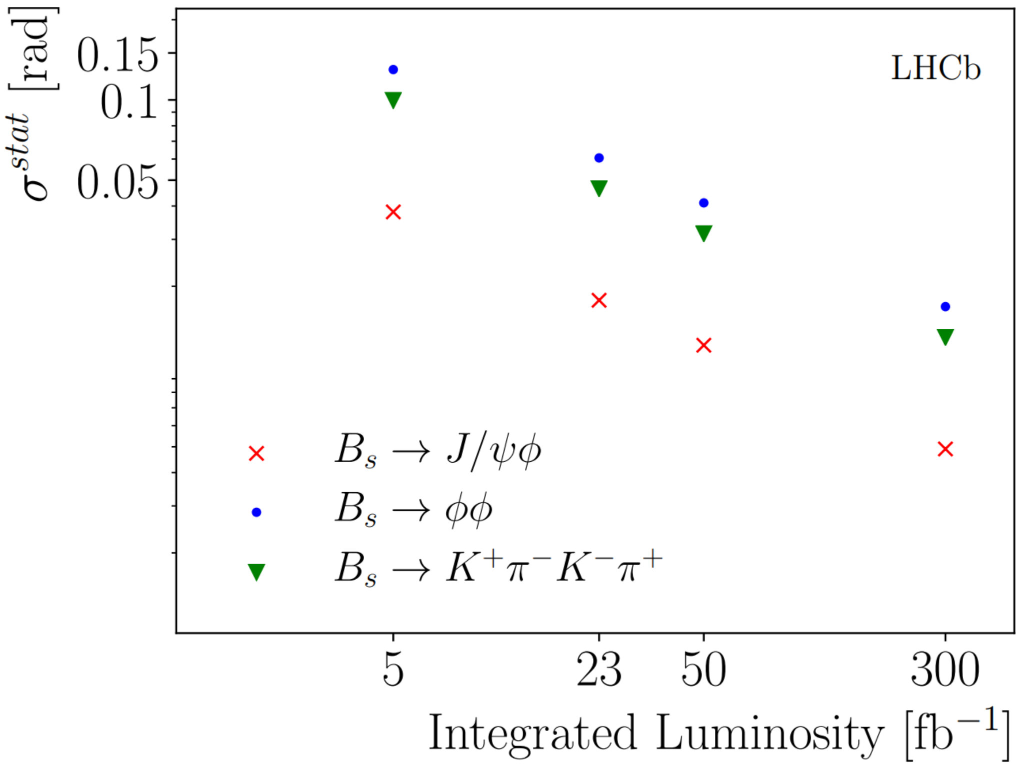
$B_s^0 \to (K^+\pi^-)(K^-\pi^+)$ JHEP 03 (2018) 140

$\phi_s^{d\bar{d}} = (-0.10 \pm 0.13 \pm 0.14)$ rad

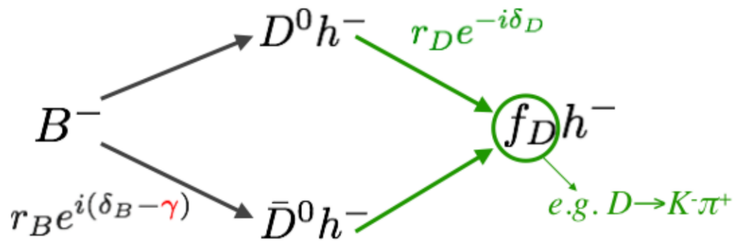
- **Precision projection**

With 25 (300) fb^{-1}, LHCb can achieve

$\sigma(\phi_s^{ss}) \sim 0.027\ (0.011)$ rad



γ from $B^{\pm} \to D(h^+h'^-\pi^0)h^{\pm}$



Method: determine γ from rates of $B \to Dh$ decays

$$\Gamma(B^{\pm} \to Dh^{\pm}) \propto |r_De^{-i\delta_D} + r_Be^{i(\delta_B \pm \gamma)}|^2$$

γ, δ_B, r_B: to be measured

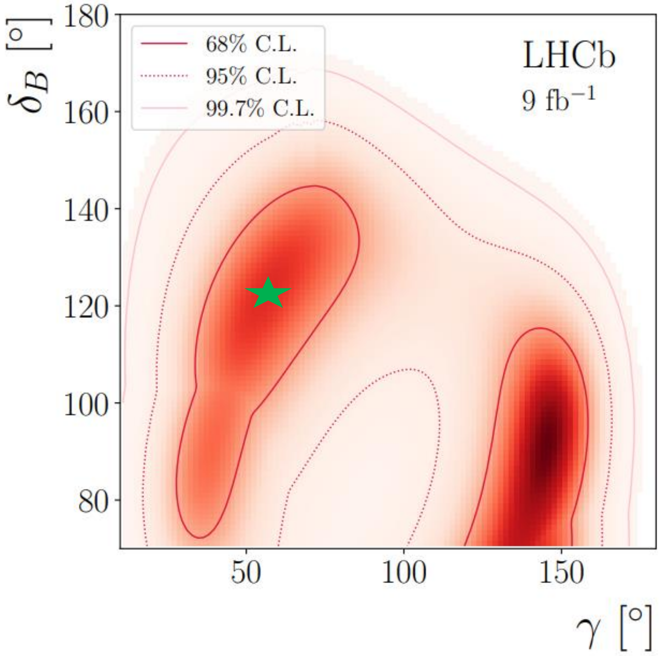
δ_D, r_D: external inputs

- Eight modes
- D parameters from BESIII using quantum-correlated $D^0\bar{D}^0$
- Two solutions. The one close to expectation is

$\gamma = (56^{+24}_{-19})^\circ$ $\delta_B = (122^{+19}_{-23})^\circ$

JHEP 07 (2022) 099

Mode	Yield
$B^{\pm} \to [K^{\pm}K^{\mp}\pi^0]_D\pi^{\pm}$	4026 ± 77
$B^{\pm} \to [\pi^{\pm}\pi^{\mp}\pi^0]_D\pi^{\pm}$	14180 ± 140
$B^{\pm} \to [K^{\pm}\pi^{\mp}\pi^0]_D\pi^{\pm}$	140696 ± 589
$B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^0]_D\pi^{\pm}$	293 ± 27
$B^{\pm} \to [K^{\pm}K^{\mp}\pi^0]_DK^{\pm}$	401 ± 29
$B^{\pm} \to [\pi^{\pm}\pi^{\mp}\pi^0]_DK^{\pm}$	1189 ± 51
$B^{\pm} \to [K^{\pm}\pi^{\mp}\pi^0]_DK^{\pm}$	12265 ± 158
$B^{\pm} \to [\pi^{\pm}K^{\mp}\pi^0]_DK^{\pm}$	155 ± 19



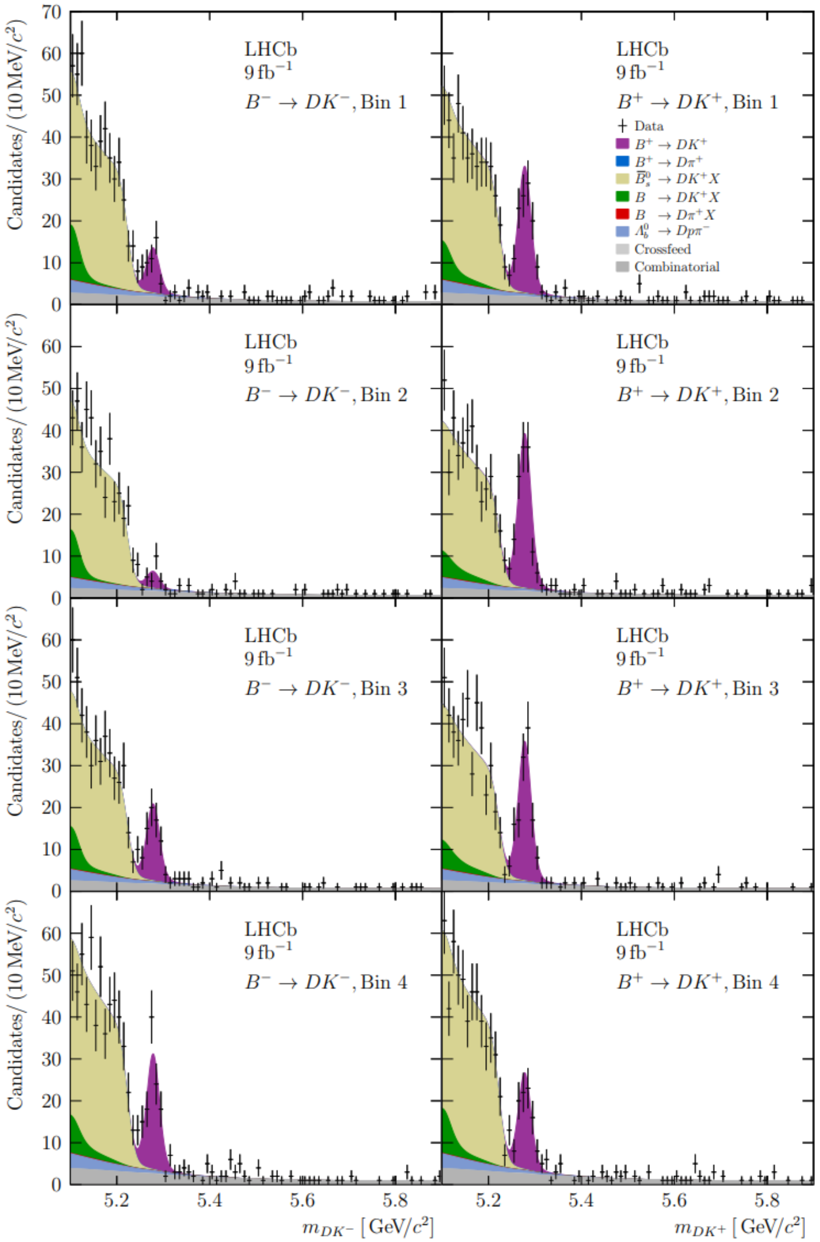
γ from $B^\pm \to D(K^\mp\pi^\pm\pi^\pm\pi^\mp)h^\pm$

- Model independent determination of γ in bins of $D \to K3\pi$ phase space
- Large CP violation effect in the disfavoured $B \to DK$ mode
- D decay coherence factors and average strong-phase differences taken from BESIII and CLEO-c

  $\Rightarrow$ Limiting factors
- One of the most precise determinations in a single mode

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

arXiv:2209.03692



LHCb γ combination

- Using Gammacombo package:

  frequentist approach with 173 beauty and charm observables to determine 52 parameters

- γ and charm mixing parameters determined

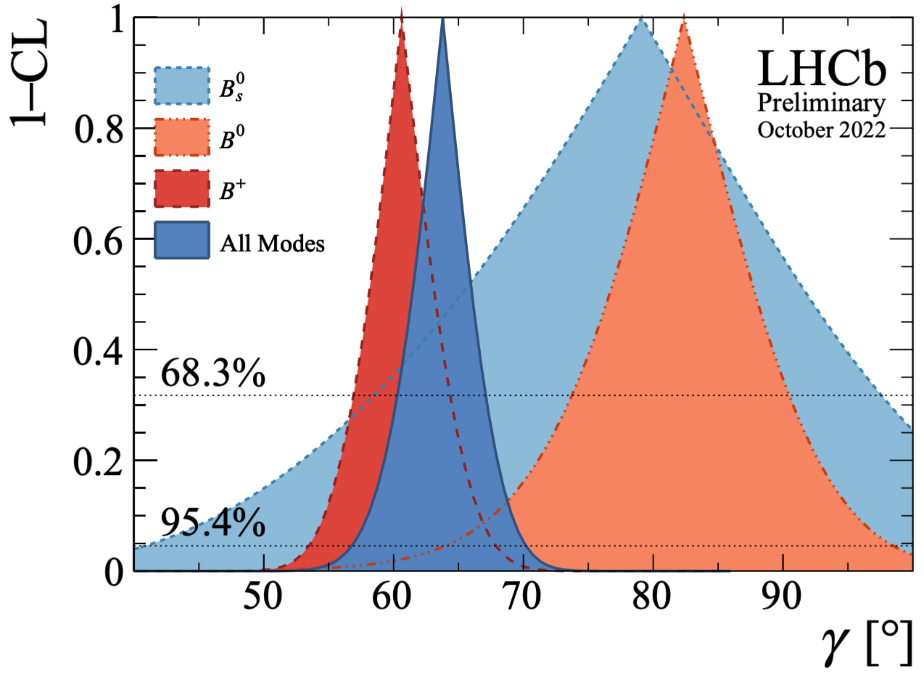
$$\gamma = (63.8^{+3.5}_{-3.7})^\circ$$
$$x_D = (0.398^{+0.050}_{-0.049})\%$$
$$y_D = (0.636^{+0.020}_{-0.019})\%$$

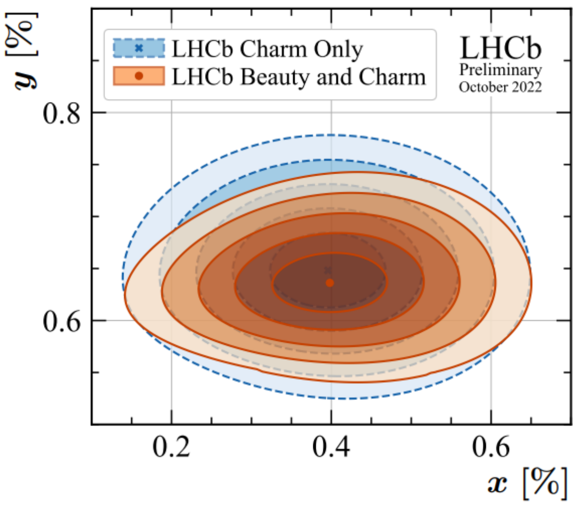
LHCb-CONF-2022-003

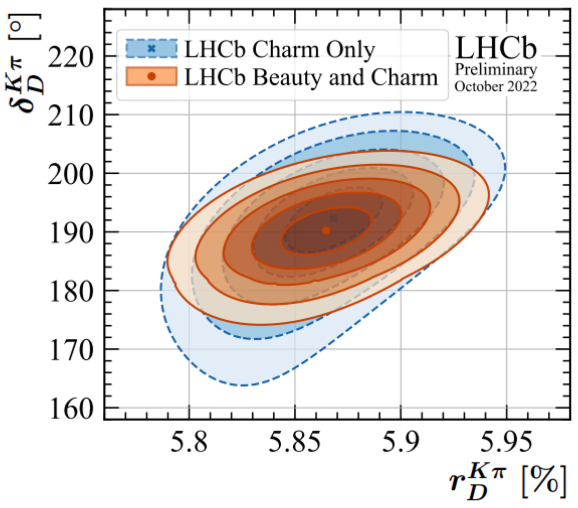
Tension between B categories (2σ)

- CKMFitter (meas. not in fit)

$$\gamma = (65.5^{+1.1}_{-2.7})^\circ$$







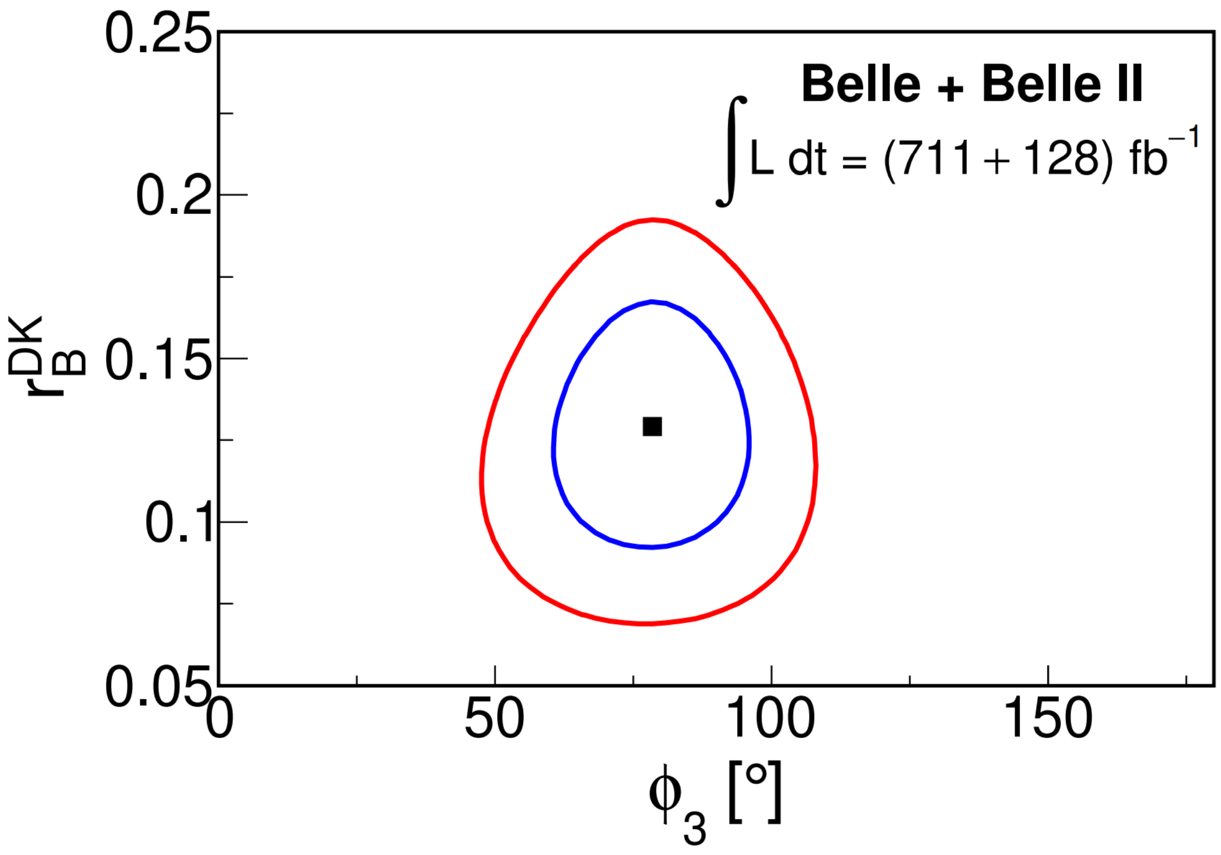
γ from $B^{\pm} \to D(K_S^0\pi^+\pi^-)h^{\pm}$

- Simultaneous analysis of 711 fb^{-1} and 128 fb^{-1} from BELLE and BELLE II
- D parameters from BESIII using quantum-correlated $D^0\overline{D}^0$
- Precision limited by data sample size

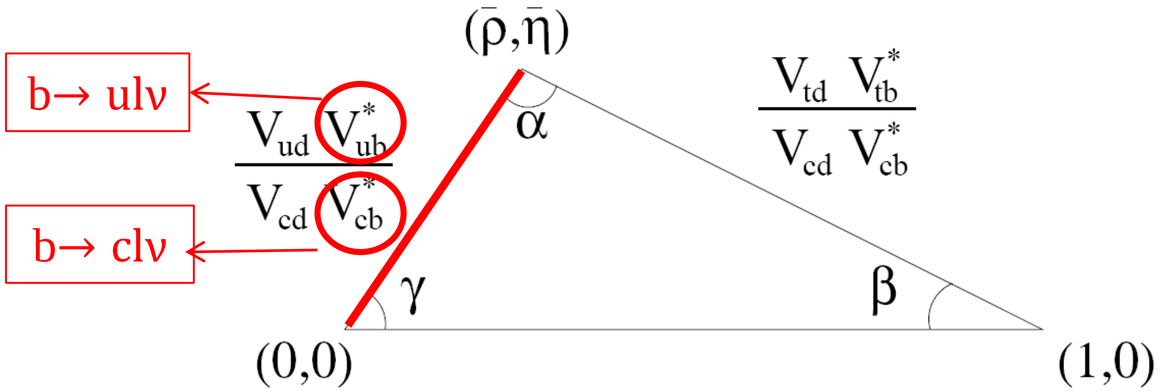
$\gamma = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)°$

JHEP 07 (2022) 099

- Expect $\sigma\gamma \sim 4°$ with 10 ab^{-1}



V_{ub}/V_{cb} measurements

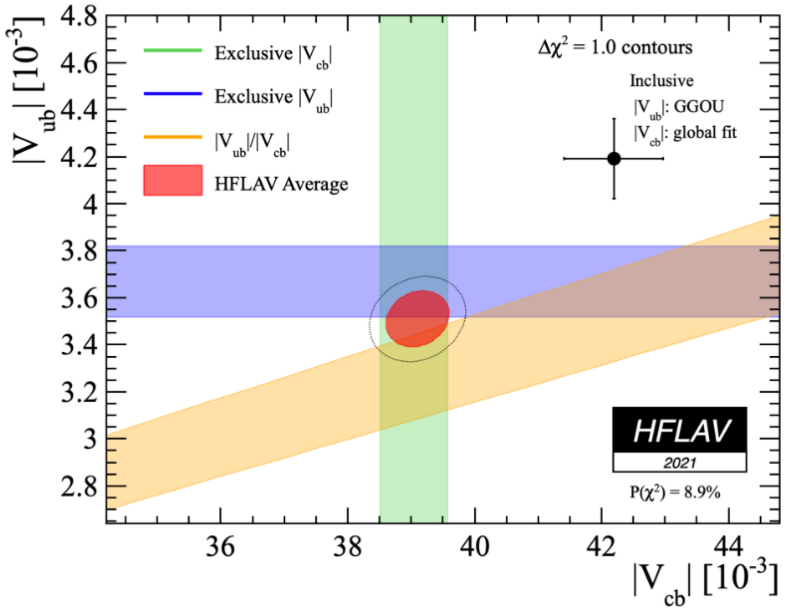


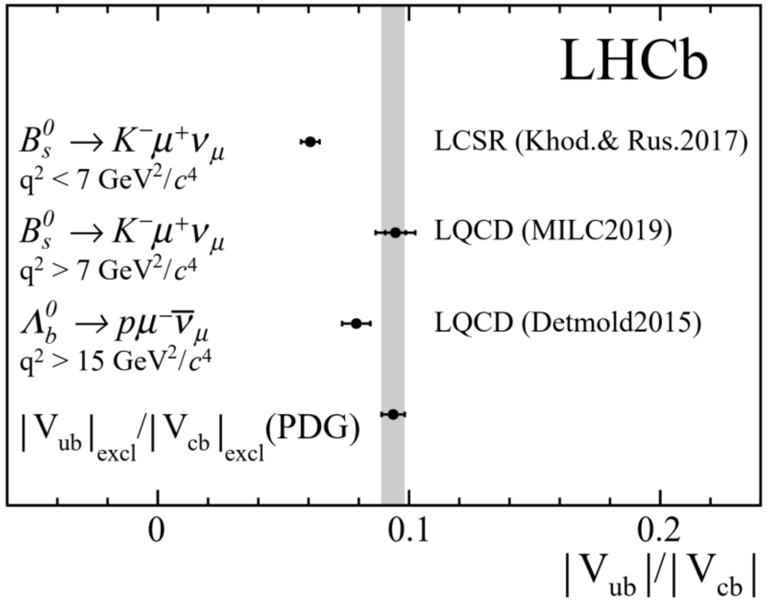
$\Lambda_b^0 \to p\mu^-\bar{\nu}_\mu$ Nature Physics 11 (2015) 743

$$\left|\frac{V_{ub}}{V_{cb}}\right| = 0.083 \pm 0.004 \pm 0.004$$

$B_s^0 \to K^-\mu^+\nu_\mu$ PRL 126 (2021) 081804

$$\left|\frac{V_{ub}}{V_{cb}}\right|(\text{low}) = 0.061 \pm 0.004,$$
$$\left|\frac{V_{ub}}{V_{cb}}\right|(\text{high}) = 0.095 \pm 0.008$$



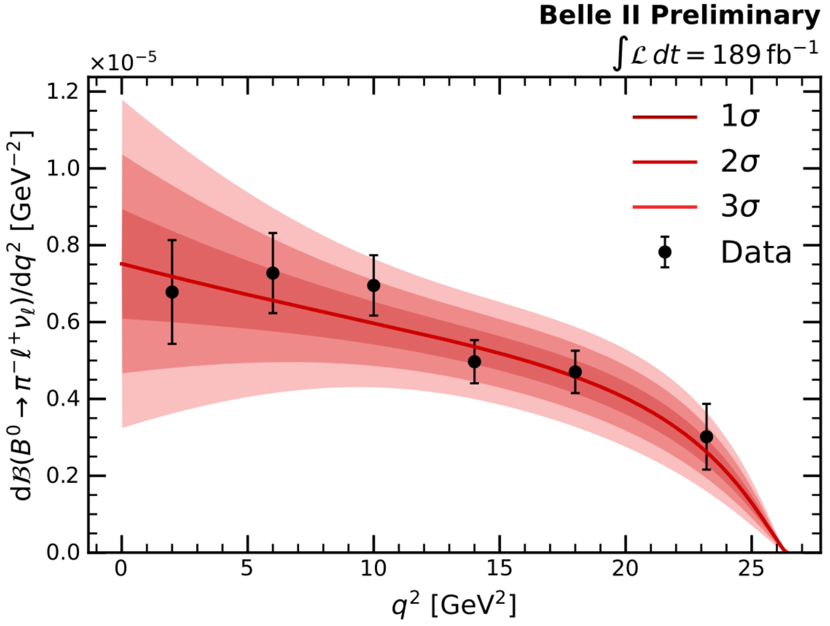


BELLE II exclusive V_{ub}

- **First measurement in $B^0 \to \pi^- l^+ \nu_l$** arXiv:2210.04224

$$\mathcal{B}(B^0 \to \pi^- l^+ \nu_l) = (1.426 \pm 0.056 \pm 0.125) \times 10^{-4}$$

$$|V_{ub}| = (3.55 \pm 0.12 \pm 0.13 \pm 0.17) \times 10^{-3}$$



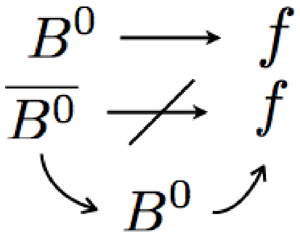
- **Promising prospects at e^+e^- machines, to be accompanied by improved Lattice QCD calculation of FFs.**

Observable	Belle	Belle II (5 ab^{-1})	Belle II (50 ab^{-1})
$\lvert V_{cb}\rvert$ incl.	1.8%	1.2%	1.2%
$\lvert V_{cb}\rvert$ excl.	$3.0_{ex} \pm 1.4_{th}$%	1.8%	1.4%
$\lvert V_{ub}\rvert$ incl.	$6.0_{ex} \pm 2.5_{th}$%	3.4%	3.0%
$\lvert V_{ub}\rvert$ excl.	$2.5_{ex} \pm 3.0_{th}$%	2.4%	1.2%

Semi-leptonic asymmetries a_{SL}^{q}

- **Using semi-leptonic B_q^0 decays**

$$a_{\rm sl} = \frac{N(\bar{B}\to B \to f) - N(B\to\bar{B} \to \bar{f})}{N(\bar{B}\to B \to f) + N(B\to\bar{B} \to \bar{f})}$$



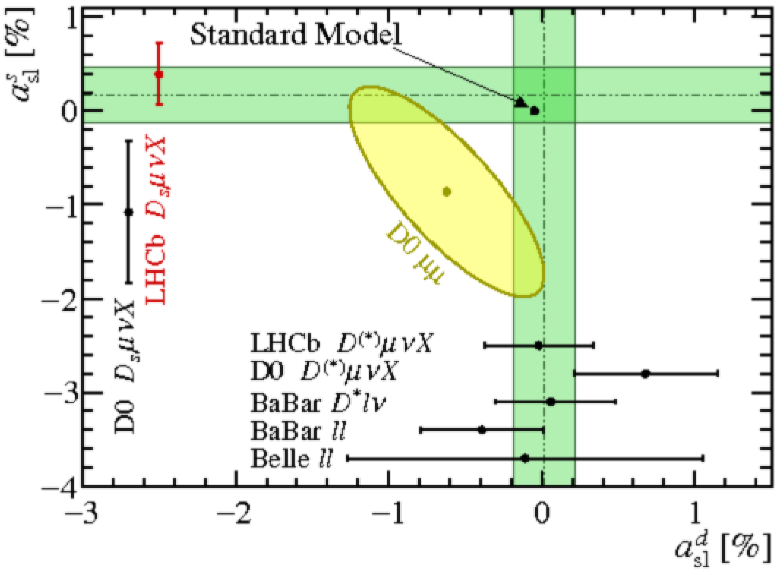
- **Most precise results from LHCb Run 1, in tension with D0 same-sign $\mu\mu$ result**

$B_s^0 \to D_s^- \mu^+ \nu$: $a_{SL}^{s} = (0.39 \pm 0.26 \pm 0.20)\%$

PRL 117 (2016) 061803

$B^0 \to D^{(*)-} \mu^+ \nu$: $a_{SL}^{d} = (-0.02 \pm 0.19 \pm 0.30)\%$

PRL 114 (2014) 041601



- **Looking forward to LHCb updates and BELLE II measurement of a_{SL}^{d}**

Direct CPV in $B \to hh'h'$

arXiv:2206.07622

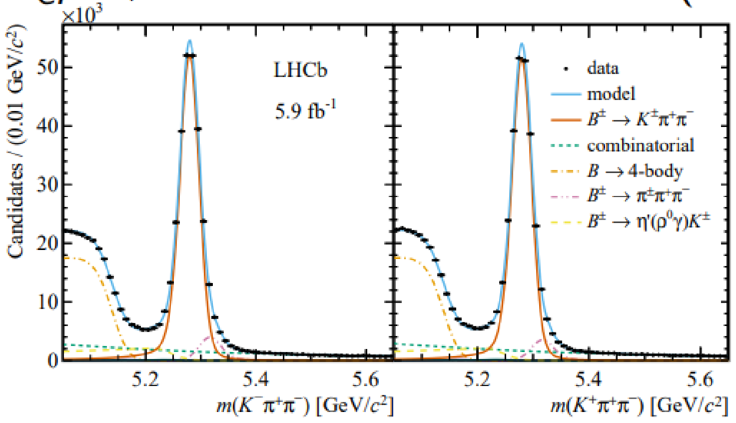
- **Direct CPV in three-body decays originates from**
  - S and P wave interference
  - KK↔ ππ rescattering
  - Long distance interactions

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

- **Experimental correction**
  - Production asymmetries
  - Detection asymmetries

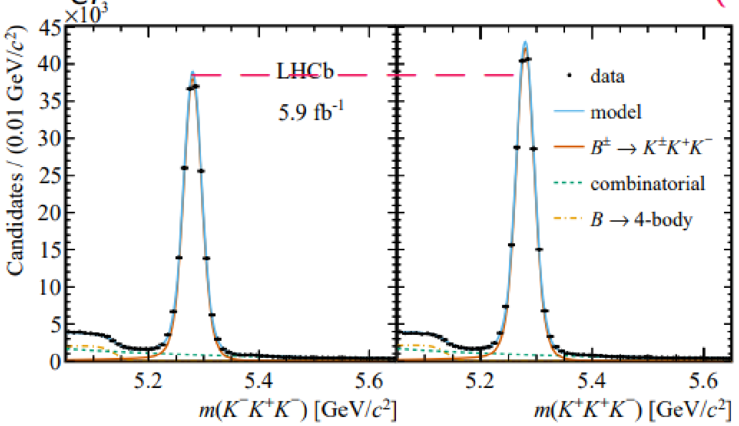
$B^\pm \to K^\pm \pi^+ \pi^-$: 499200±900

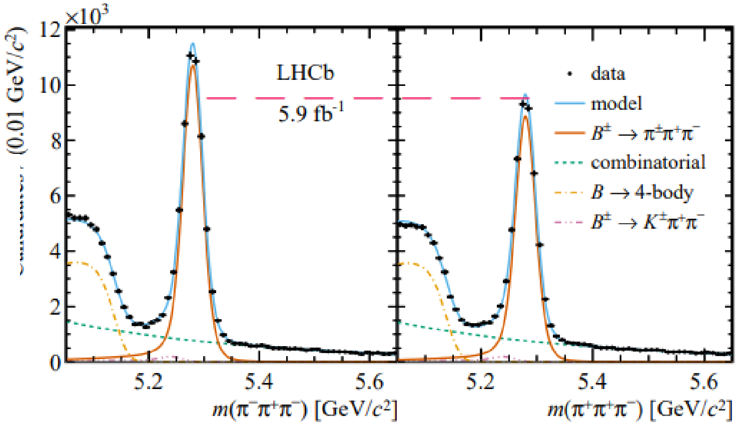
A_{CP}=+0.011±0.002±0.003±0.003 (2.4σ)

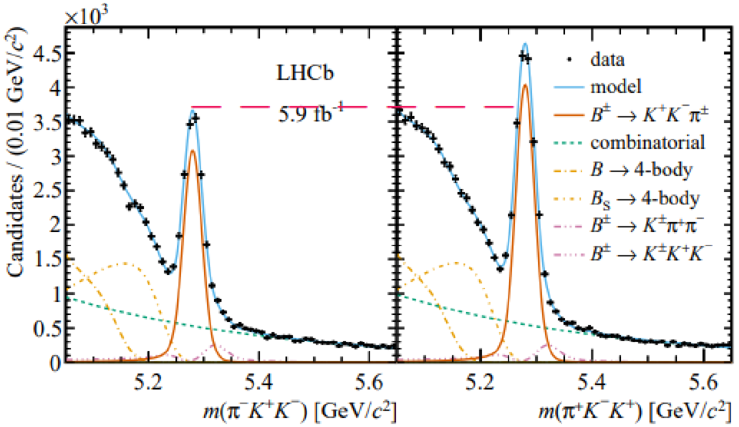


$B^\pm \to K^\pm K^+ K^-$: 365000±1000

A_{CP}=−0.037±0.002±0.002±0.003 (8.5σ)







$B^\pm \to \pi^\pm \pi^+ \pi^-$: 101000±500

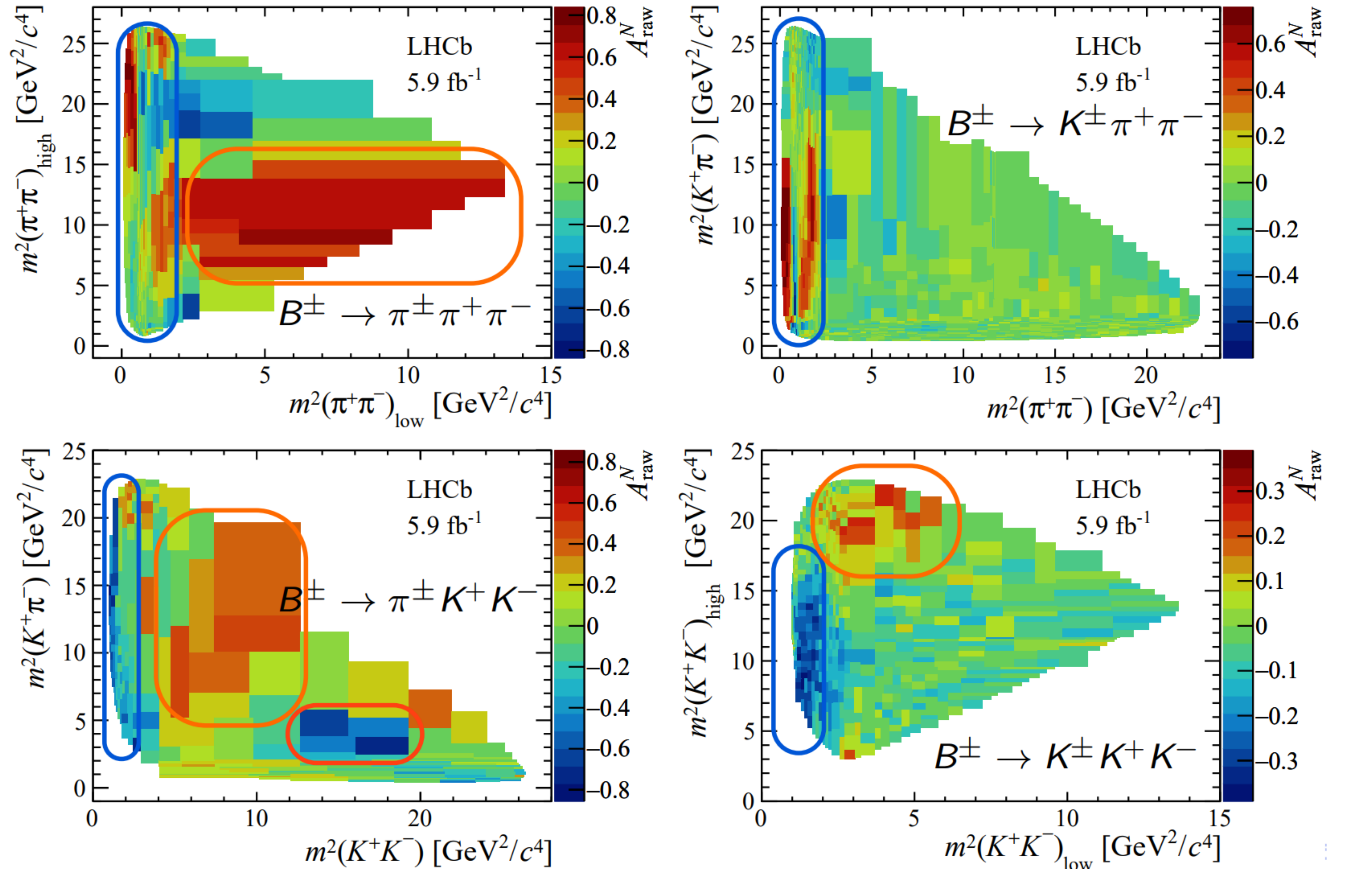
A_{CP}=+0.080±0.004±0.003±0.003 (14.1σ)

$B^\pm \to \pi^\pm K^+ K^-$: 32470±300

A_{CP}=−0.114±0.007±0.003±0.003 (13.6σ)

Localized CPV in $B \to hh'h'$

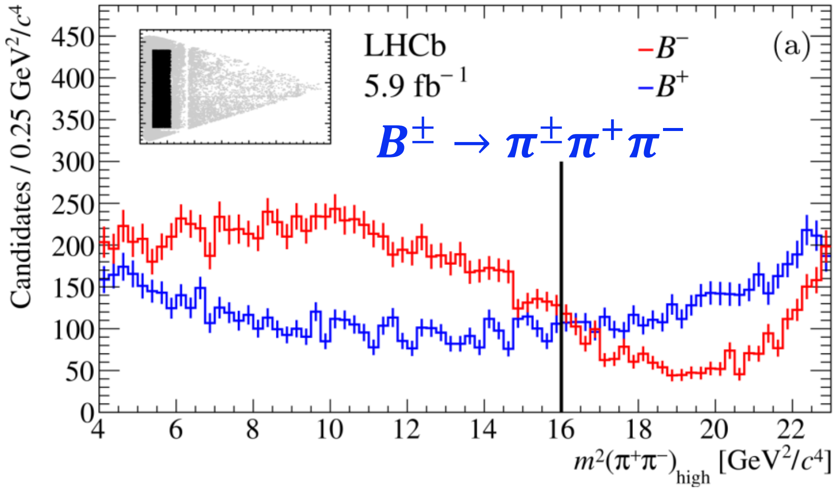
arXiv:2206.07622

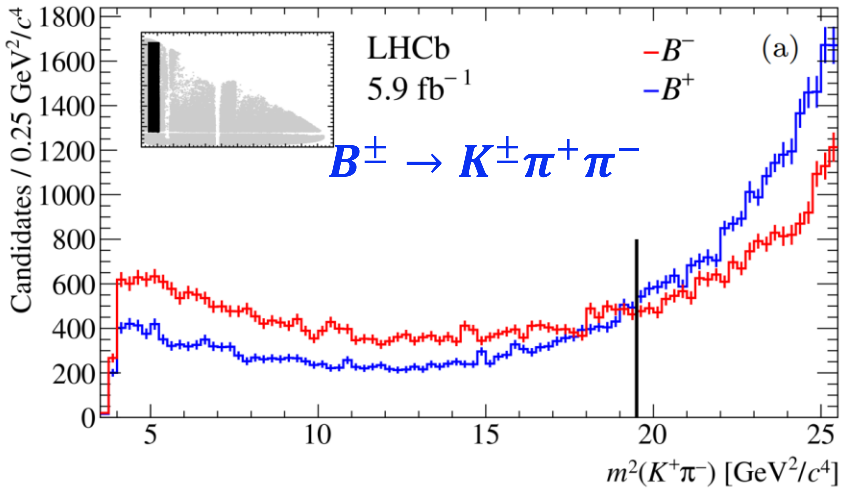


Localized CPV in $B \to hh'h'$

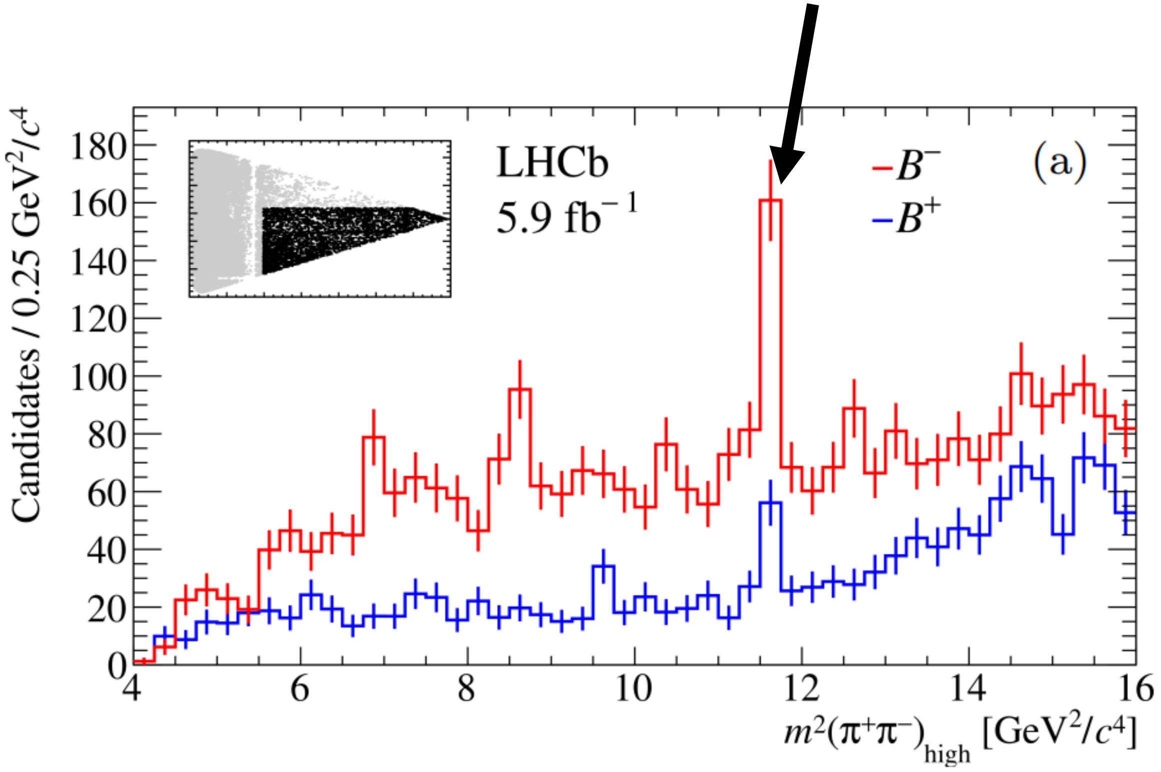
arXiv:2206.07622

- A_{CP} changes sign with $m(hh')$ in KK↔ ππ rescattering region





- What is the origin of the large $A_{CP} = (74.5 \pm 2.7 \pm 1.8)\%$ in $m^2_{low}(\pi^+\pi^-) < 15$ GeV^2 region, including charmonium $\chi_{c0}(1P)$?



Recent $A_{CP}(B \to K^+\pi^0)$

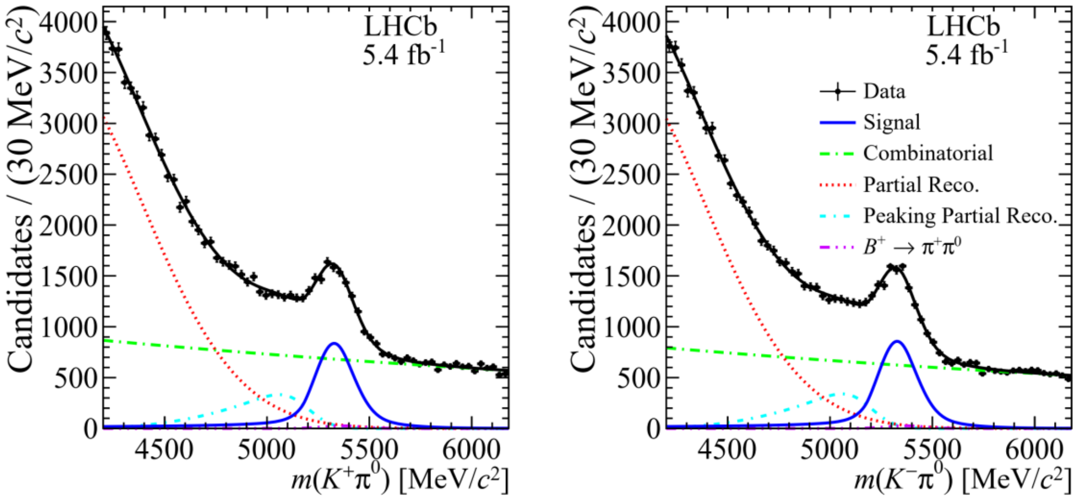
- Isospin symmetry: $\Delta A_{CP}(K\pi) = A_{CP}(K^+\pi^0) - A_{CP}(K^-\pi^+) \approx 0$.

  World average : $\Delta A_{CP}(K\pi) \approx 0.122 \pm 0.021$, 5.5σ from zero!

  Uncertainty dominated by $A_{CP}(K^+\pi^0) = 0.040 \pm 0.021$

5.4 fb^{-1} Run 2

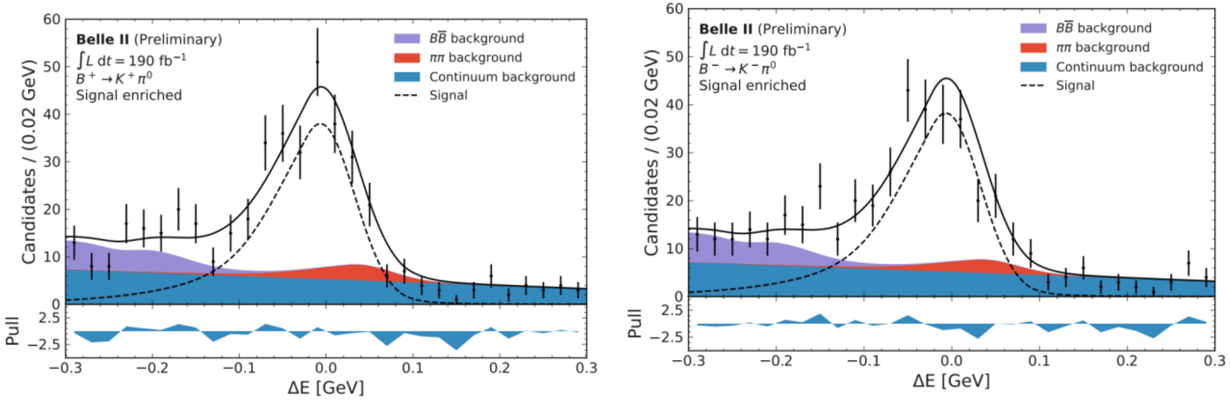
PRL 126 (2021) 091802



$A_{CP}(K^+\pi^0) = 0.025 \pm 0.015 \pm 0.006 \pm 0.003$

First 190 fb^{-1}

arXiv:2209.05154



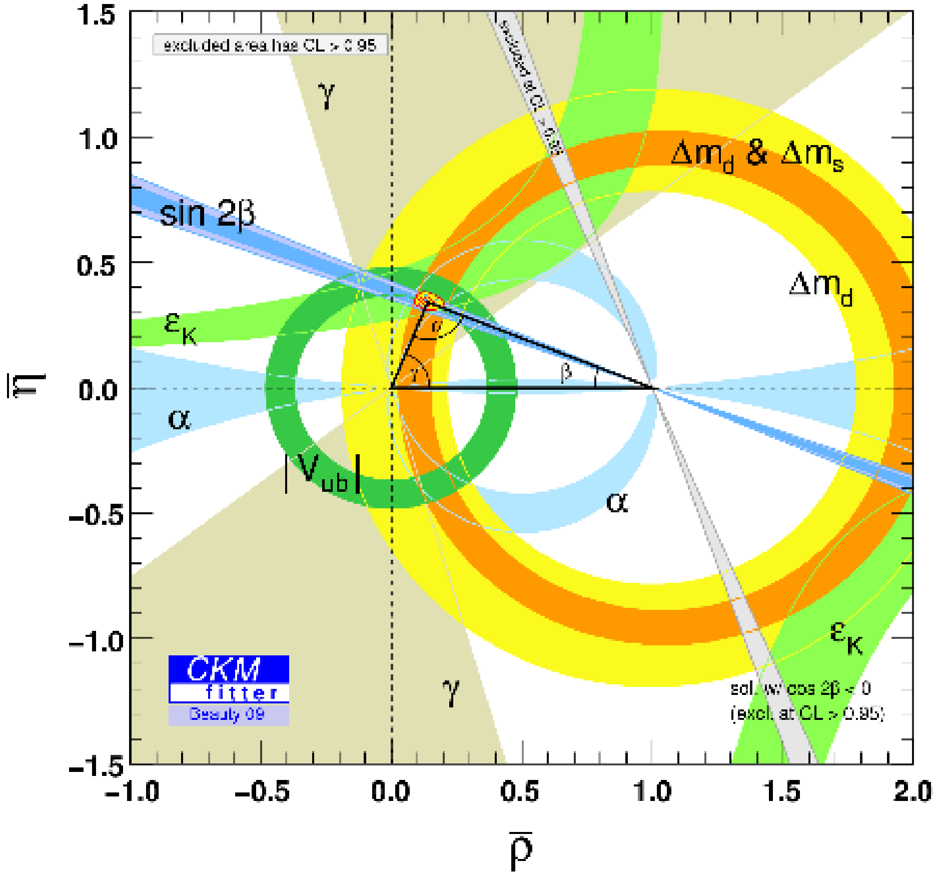
$A_{CP}(K^+\pi^0) = 0.014 \pm 0.047 \pm 0.010$

New WA: $A_{CP}(K^+\pi^0) = 0.031 \pm 0.013$

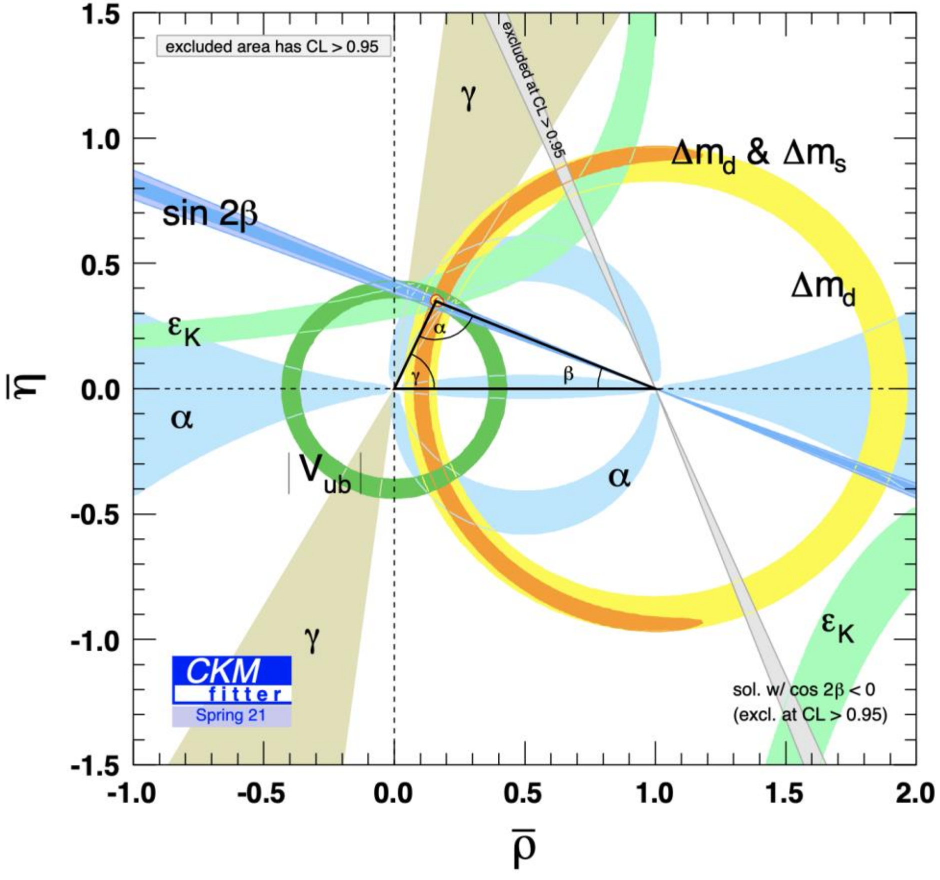
$\Delta A_{CP}(K\pi) = 0.115 \pm 0.014$ (8σ from zero)

Global CKM fits

When LHC started



Current picture



p-value ~ 29%

Flavour and CP violation in quark sector well described by CKM mechanism!

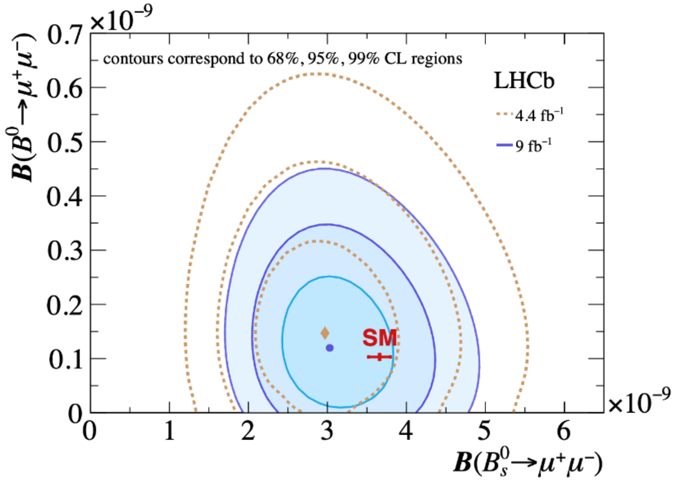
Rare decays &
lepton flavour universality tests

Leptonic B decays

- $B_s^0 \to \mu\mu$ branching fraction consistent with SM

LHCb, PRL 128, (2022) 041801

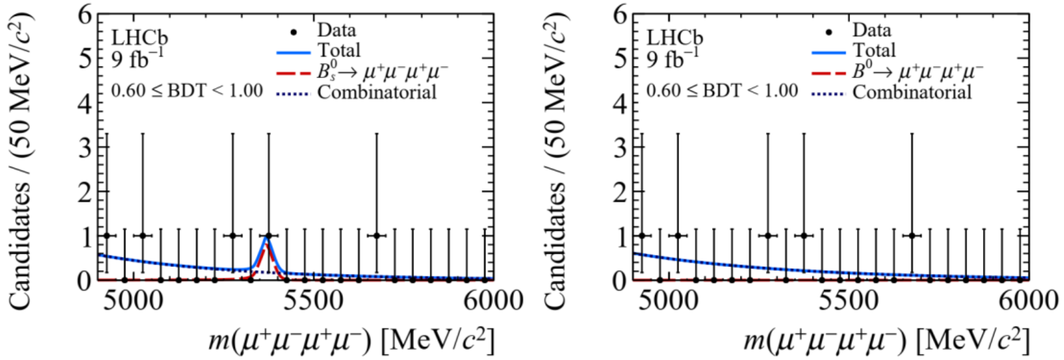
	$B(B_s^0 \to \mu^+\mu^-)$	$B(B^0 \to \mu^+\mu^-)$
LHCb (11-18)	$\left(3.09^{+0.46}_{-0.43}{}^{+0.15}_{-0.11}\right) \times 10^{-9}$	$< 2.6 \times 10^{-10}$
CMS (11-16)	$(2.9 \pm 0.7 \pm 0.2) \times 10^{-9}$	$< 3.6 \times 10^{-10}$
ATLAS (11-16)	$\left(2.8^{+0.8}_{-0.7}\right) \times 10^{-9}$	$< 2.1 \times 10^{-10}$
SM	$(3.66 \pm 0.14) \times 10^{-9}$	$(1.03 \pm 0.05) \times 10^{-9}$



- Searches for B decays to four muons

LHCb, JHEP 03 (2022) 109

$$B\left(B_s^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 8.6 \times 10^{-10} \text{ at } 90\% \text{ CL}$$
$$B\left(B^0 \to \mu^+\mu^-\mu^+\mu^-\right) < 1.8 \times 10^{-10} \text{ at } 90\% \text{ CL}$$



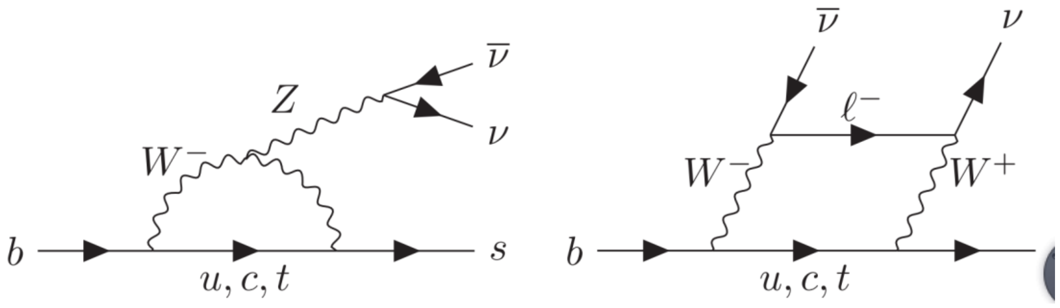
- LHCb upgrade II: 10% precision for $B(B^0 \to \mu\mu)$ / $B(B_s^0 \to \mu\mu)$, 2% for $\tau^{\text{eff}}(B_s^0 \to \mu\mu)$
- e^+e^- machines: search for $B^0 \to \nu\bar{\nu}$?

Searches for $B^+ \to K^+\nu\bar{\nu}$

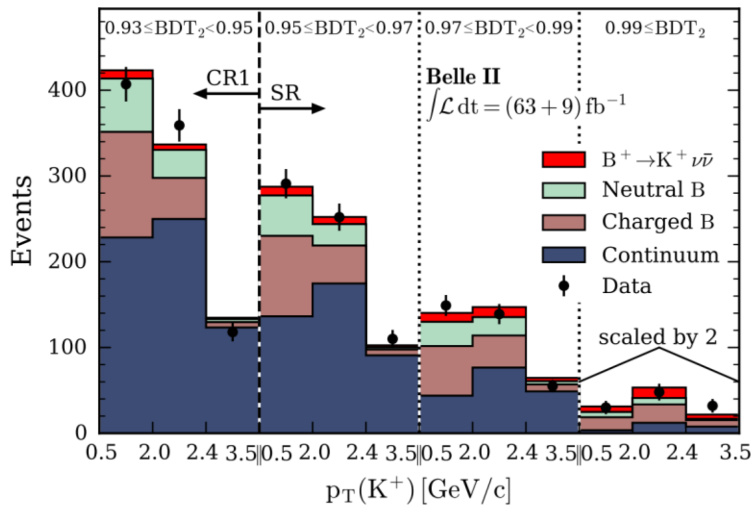
- **SM prediction**

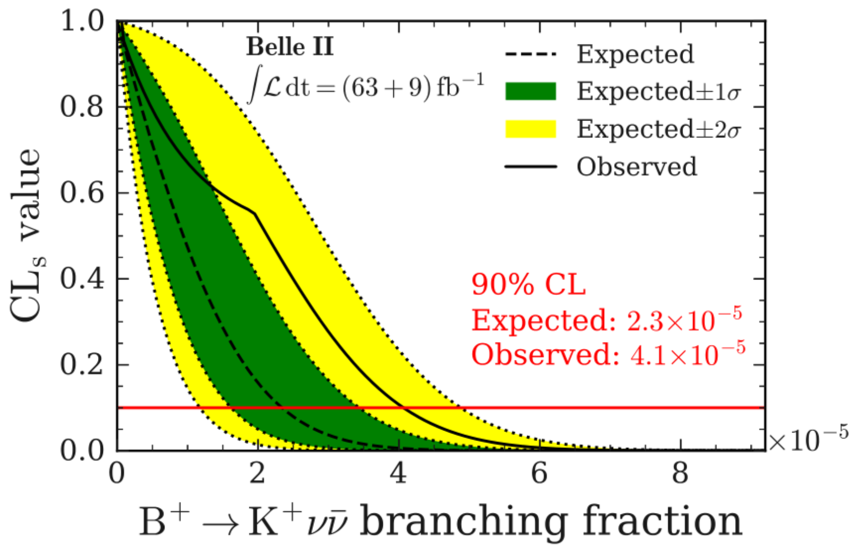
$\mathrm{B}(B^+ \to K^+\nu\bar{\nu}) = (4.7 \pm 0.6) \times 10^{-6}$

A. J. Buras et al., JHEP 02 (2015) 0684



- **Search result with 63 fb^{-1}** PRL 127 (2021) 181802





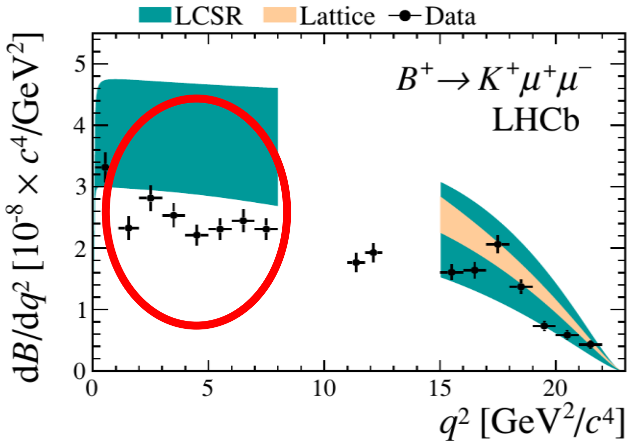
$\mathrm{B}(B^+ \to K^+\nu\bar{\nu}) < 4.1 \times 10^{-5}$ at 90% CL

$b \to s\mu^+\mu^-$ decay rates

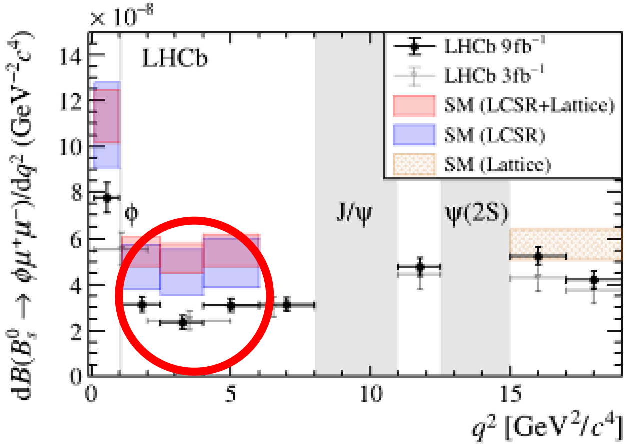
- **Branching fractions systematically below SM at low q^2**

  Caveat: significant hadronic uncertainties ⇒ look at more robust observables

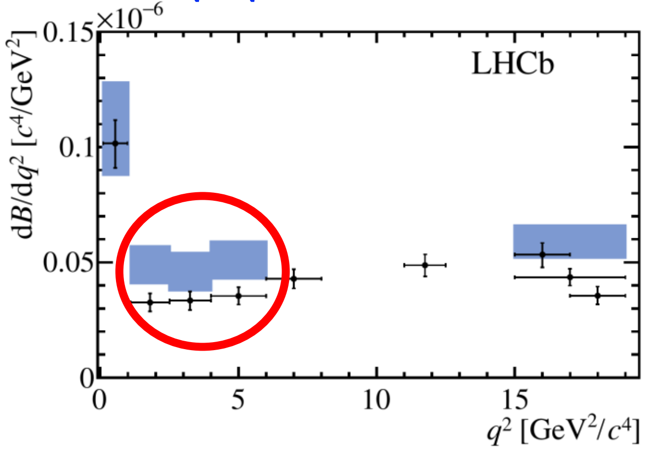
$B^+ \to K^+\mu^+\mu^-$ JHEP 06(2014)133



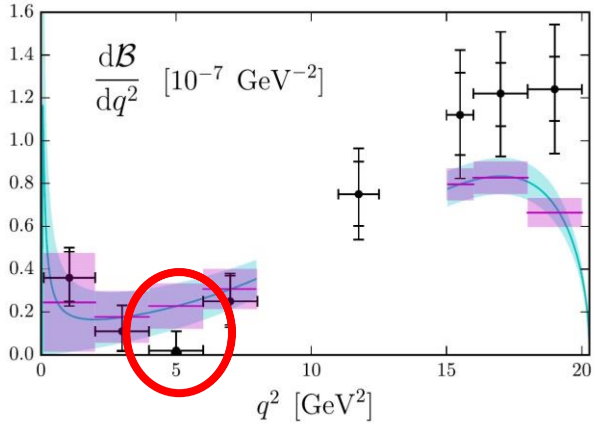
$B_s^0 \to \phi\mu^+\mu^-$ arXiv: 2105.14007



$B^0 \to K^{*0}\mu^+\mu^-$ JHEP 04(2017)142

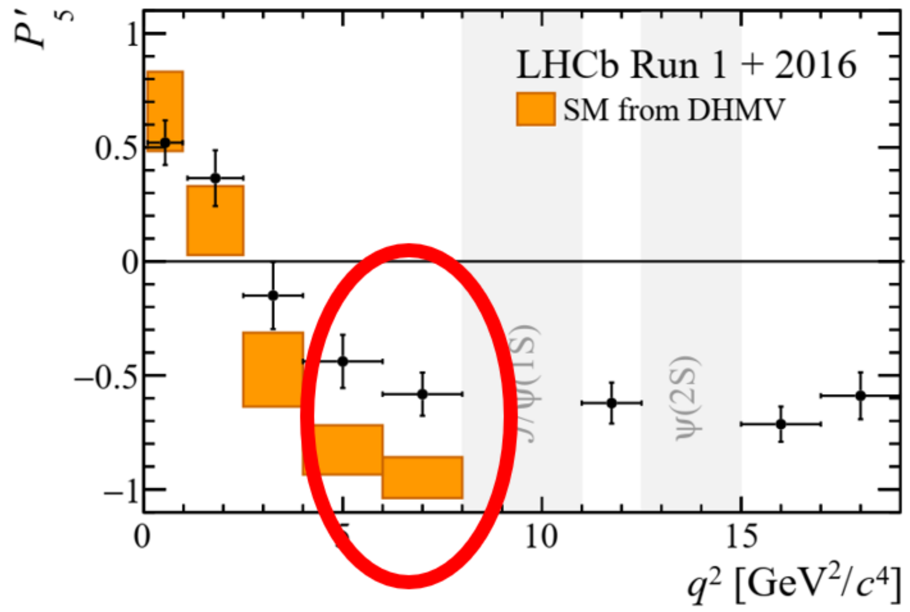


$\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$ JHEP 06(2015)115



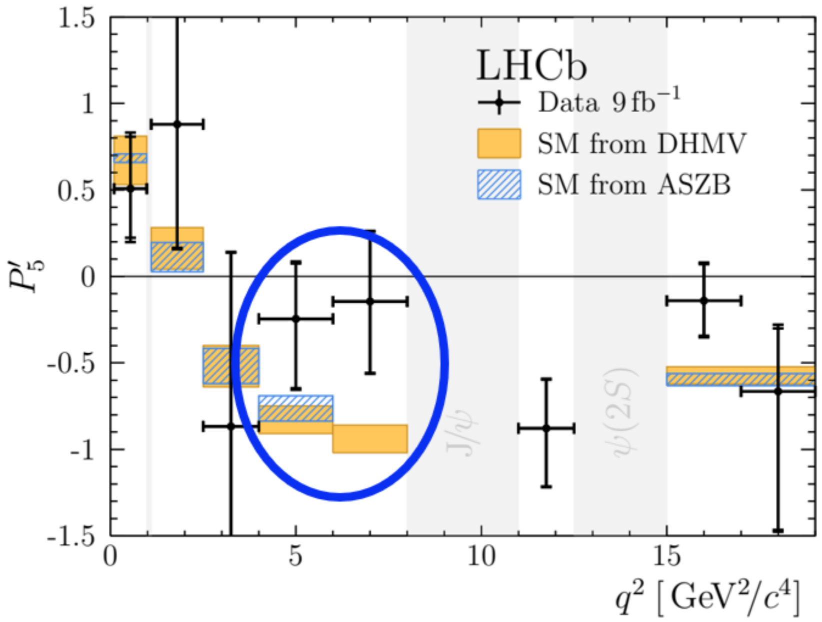
Angular coefficients in $B \to K^* \mu^+ \mu^-$

$B^0 \to K^{*0} \mu^+ \mu^-$ PRL 125 (2020) 011802



P'_5 values $2-3\sigma$ from SM in
$4 < q^2 < 8$ GeV^2 region

$B^+ \to K^{*+} \mu^+ \mu^-$ PRL 126 (2021) 091802



P_2 values 3σ from SM in
$4 < q^2 < 8$ GeV^2 region

LFU tests in $b \to s l^+ l^-$

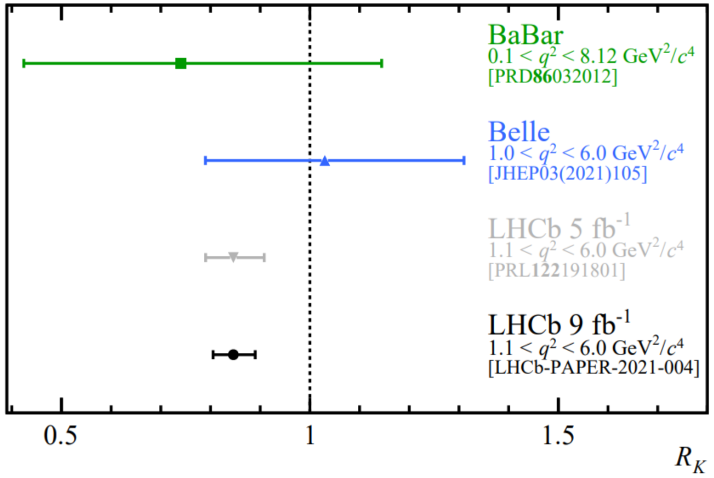
$$R(X) = \mathrm{B}(B \to X\mu^+\mu^-)/\mathrm{B}(B \to X e^+ e^-)$$

- **$R(X)$ is expected to be very close to unity in the SM**
- **Measurements of $R(K), R(K_S^0), R(K^{*0}), R(K^{*+}), R(pK)$ lower than SM values by $2-3\sigma$**

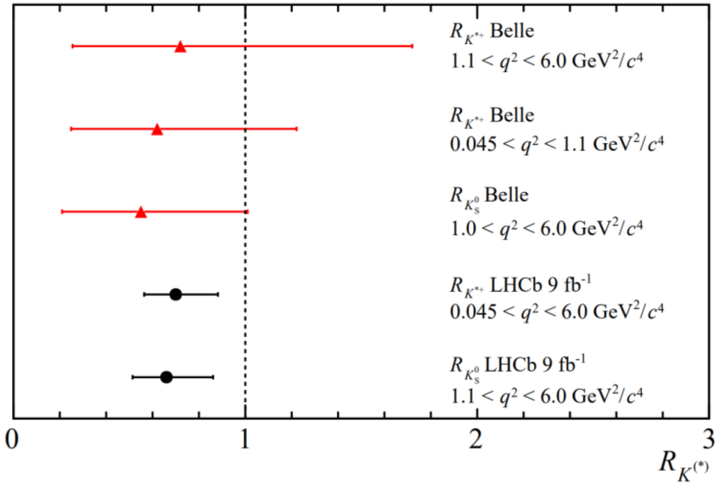
Nature Physics 18 (2022) 277, JHEP 05 (2020) 040, JHEP 08 (2017) 055, PRL 128 (2022) 19

- **Higher precision and better understanding of systematics needed**

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



$B^0 \to K_S^0 l^+ l^-, B \to K^* l^+ l^-$



LFU tests in $b \rightarrow c l^- \nu_l$

PRL 126 (2021) 091802

$$R(D^{(*)}) = \frac{\mathrm{B}(\bar{B} \rightarrow D^{(*)} \tau^- \bar{\nu}_\tau)}{\mathrm{B}(\bar{B} \rightarrow D^{(*)} \mu^- \bar{\nu}_\tau)}$$

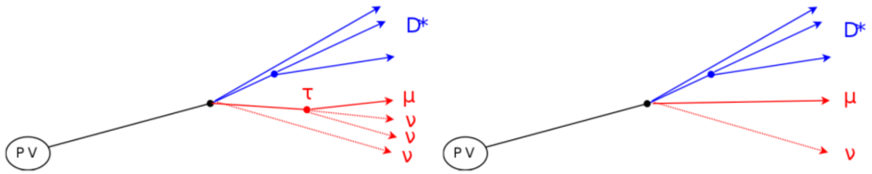
- **Previously only measure**

  $R(D^*) = 0.336 \pm 0.27 \pm 0.030$

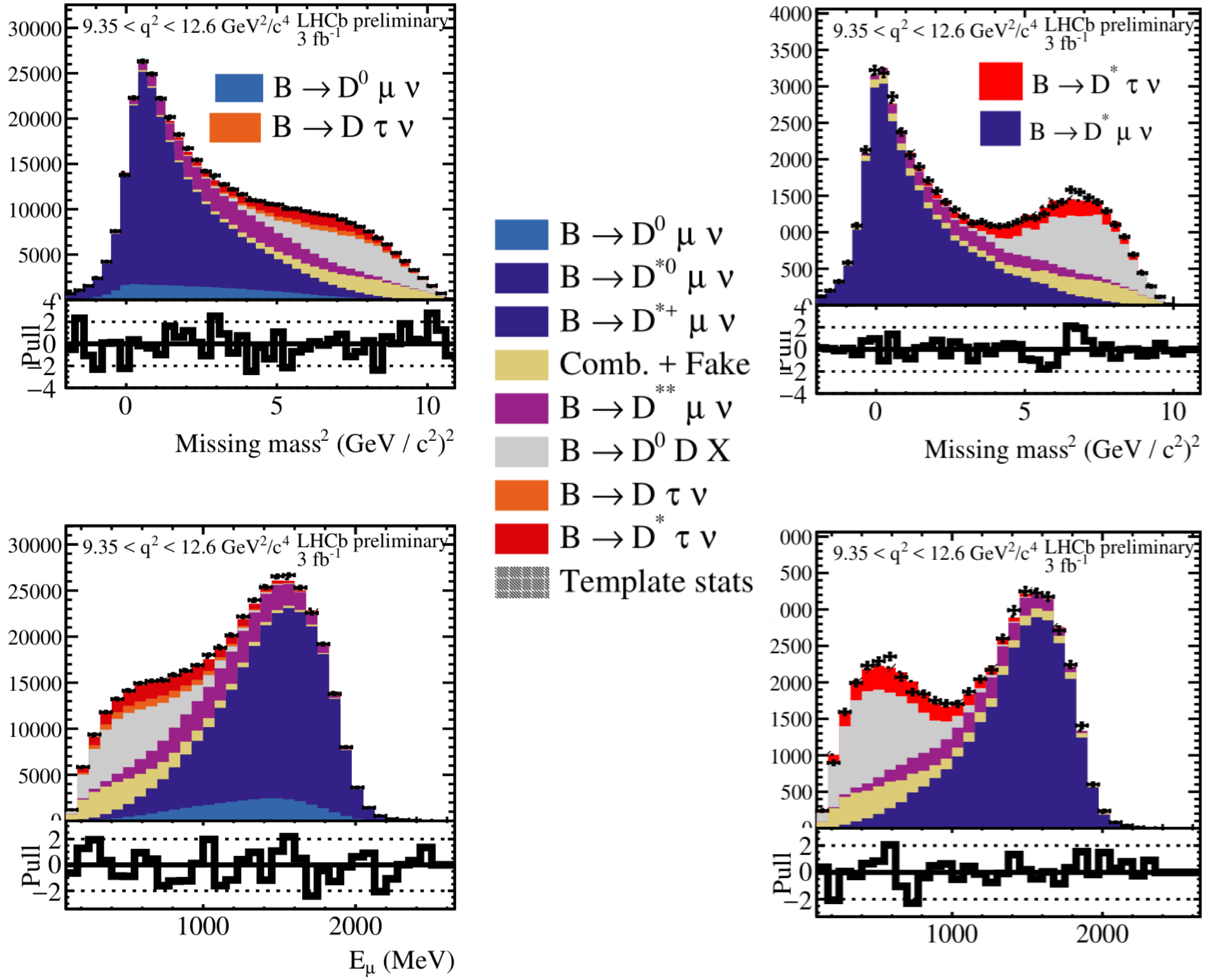
- **Now simultaneously measure**

$R(D^*) = 0.281 \pm 0.018 \pm 0.024$
$R(D) = 0.441 \pm 0.060 \pm 0.066$
$\rho = -0.43$

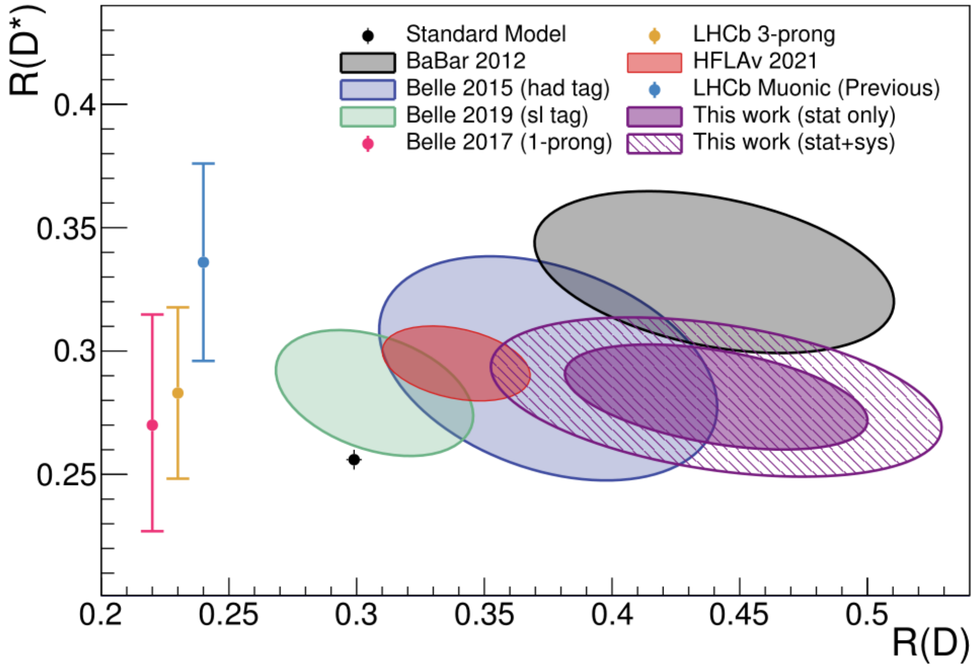
$\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau$ $\bar{B}^0 \rightarrow D^{*+} \mu^- \bar{\nu}_\mu$

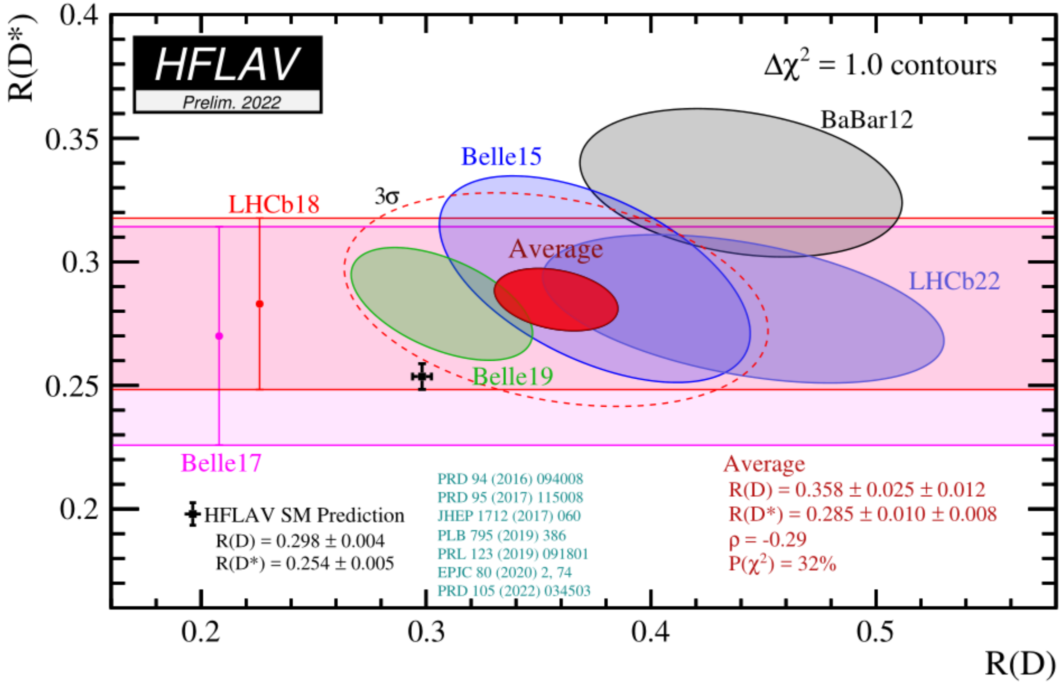


$D^0 \mu^-$ sample $D^{*+} \mu^-$ sample



$R(D^{(*)})$ average





New LHCb result:

- 1.9σ agreement with SM
- Good agreement with other meas.

New preliminary average:

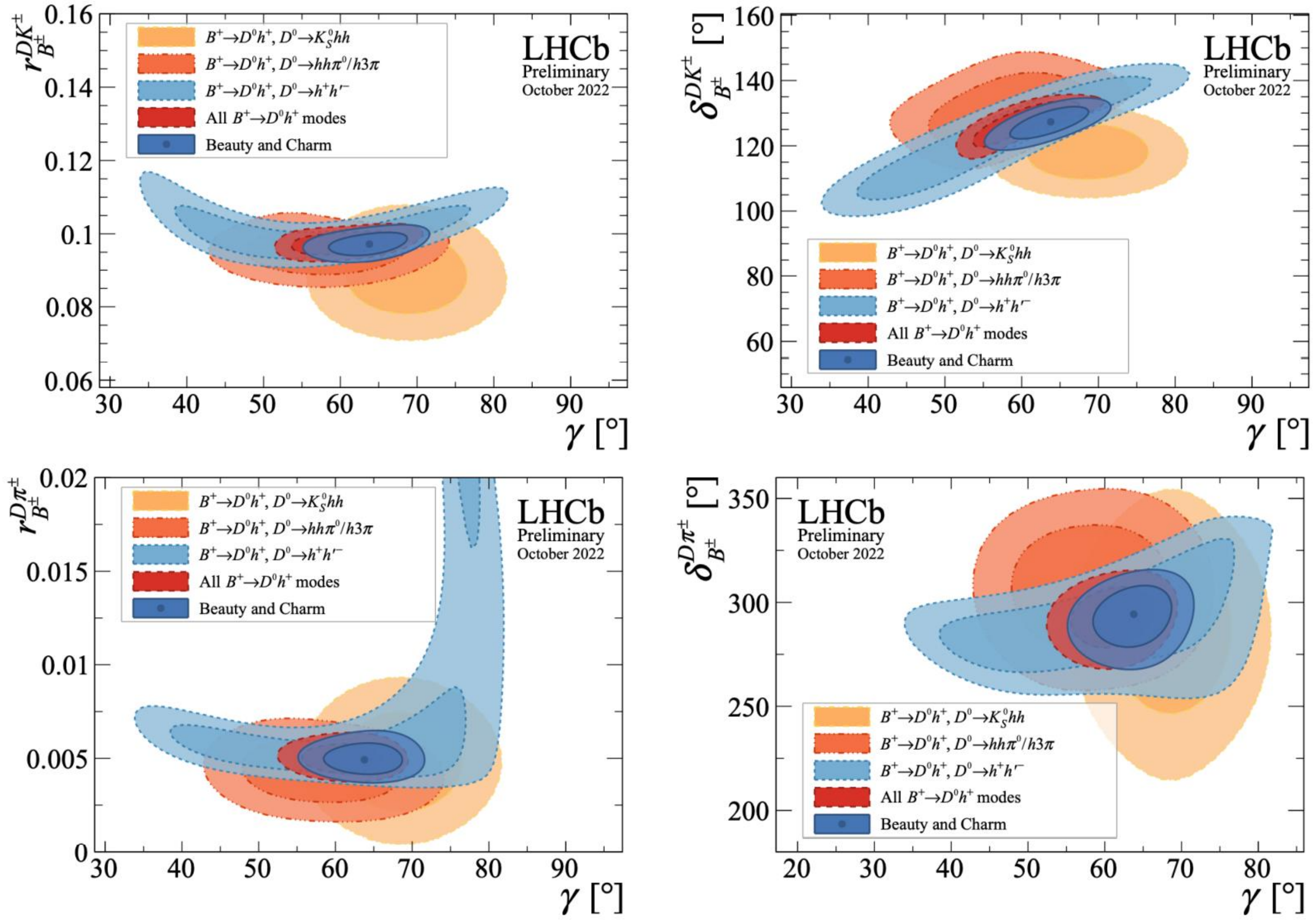
- Slighter higher $R(D)$ and lower $R(D^*)$
- $3.2\sigma \rightarrow 3.3\sigma$ agreement with SM

Conclusions

- **Past decade: LHCb has significantly influenced the field of flavour physics**
  - Remarkable improvements in precision of CKM parameters
  - Deep exploration of the B_s^0 system
  - Observation of a series of flavour anomalies
  - Discoveries of many new hadron states
- **Next decade: LHCb and BELLE II will be the major players in flavour physics and complement each other**
  - LHCb will exploit the large pp cross section to further improve the measurement precision of CP violation and rare decays
  - BELLE II has unique strengths to study inclusive decays, decays to neutrinos or stable neutral particles
- **It is time to prepare for the further future: flavour physics at CEPC**

LHCb γ combination

- Contributions of different decay modes agree with each other



$B^\pm \to \rho(770)^0 K^\pm$

arXiv:2206.02038

- For isolated vector resonances, $A_{CP} \propto$ square modulus of amplitude difference

$$|\mathcal{M}_\pm|^2 = \underbrace{p_0^\pm}_{\text{Direct scalar } A_{CP}} + \underbrace{p_1^\pm \cos\theta(m_V^2, s_\perp)}_{\text{Scalar and Vector interf.}} + \underbrace{p_2^\pm \cos^2\theta(m_V^2, s_\perp)}_{\text{Direct vector } A_{CP}}$$

* model independent analysis of quasi two-body decays of $B^+ \to R(h_1^- h_2^+) h_3^+$:
$s_{||} = m^2(h_1^- h_2^+)$, $s_\perp = m^2(h_1^- h_3^+)$

$p_2^\pm$ obtained from a simple quadratic fit:

$$A_{CP}^V = \frac{|\mathcal{M}_-|^2 - |\mathcal{M}_+|^2}{|\mathcal{M}_-|^2 + |\mathcal{M}_+|^2} = \frac{p_2^- - p_2^+}{p_2^- + p_2^+}$$

- A large CP asymmetry found in $B^\pm \to \rho(770)^0(\pi^+\pi^-)K^\pm$ decays

$A_{CP} = (15.0 \pm 1.9_{\rm stat} \pm 1.1_{\rm syst} \pm 0.3_{J/\psi K})\%$

(6.8 σ)

No isolation of $\rho(770)^0$ contribution from the influence of $\omega(782)$ resonance