HFLAV news

Mirco Dorigo

INFN TRIESTE

2025 Belle II Physics Week

October 6th, 2025

HFLAV

What word comes to mind?

https://app.wooclap.com/GPBUBC

https://hflav.web.cern.ch/

HFLAV Heavy Flavor Averaging Group

The Heavy Flavor Averaging Group

The Heavy Flavor Averaging Group (HFLAV) was established at the May 2002 Flavor Physics and CP Violation Conference (Philadelphia) and continues the LEP Heavy Flavor Steering Group's tradition of providing regular updates to the world averages of heavy flavor measurements.

Our report *Averages of b-hadron, c-hadron, and tau-lepton properties as of 2023* presents the latest averages. See an overview in this summary or browse the full results with online updates from each working group:

- b-hadron lifetimes and oscillation parameters
- Semi-leptonic B decays
- Rare B decays
- Unitarity triangle angles
- B decays to charm final states
- Charm CP violation and oscillations
- Charm decays
- Tau Physics

Check out our full list of publications *Averages of b-hadron, c-hadron, and τ-lepton properties as of ...*

- *2023* arXiv:2411.18639
- *2021* arXiv:2206.07501, Phys. Rev. **D107**, 052008
- *2018* arXiv:1909.12524, Eur. Phys. J. **C81** (2021), 226
- *2016* arXiv:1612.07233, Eur. Phys. J. **C77** (2017), 895
- *2014* arXiv:1412.7515
- *2012* arXiv:1207.1158
- *2010* arXiv:1010.1589

arXiv:2411.18639

Averages of b-hadron, c-hadron, and τ-lepton properties as of 2023

Heavy Flavor Averaging Group (HFLAV):

Sw. Banerjee, E. Ben-Haim, F. Bernlochner, E. Bertholet, M. Bona, A. Bozek, C. Bozzi, J. Brodzicka, V. Chobanova, M. Chrzaszcz, U. Egede, M. Gersabeck, P. Goldenzweig, N. Gharbi, L. Grillo, K. Hayasaka, T. Humair, D. Johnson, T. Kuhr, O. Leroy, A. Lusiani, H.-L. Ma, M. Margoni, R. Mizuk, P. Naik, T. Nanut Petrič, A. Pereiro Castro, M. Prim, M. Roney, M. Rotondo, O. Schneider, C. Schwanda, A. J. Schwartz, J. Serrano, B. Shwartz, A. Soffer, M. Whitehead and J. Yelton

December 2, 2024

To appear soon in PRD.

The people

A strong collective effort from different experiments

The co-leaders of HFLAV are **Mirco Dorigo** (INFN Trieste, Belle II) mirco.dorigo@ts.infn.it and **Ulrik Egede** (Monash University, LHCb) ulrik.egede@monash.edu

Oscillations

- Marcella Bona (Queen Mary University of London, ATLAS)
- **Veronika Chobanova** (University of A Coruña, LHCb)
- Thibaud Humair (DESY, Belle II)
- Olivier Leroy (CPPM Marseille, LHCb)
- Martino Margoni (Padova, CMS)
- Olivier Schneider (EPFL Lausanne, Belle / LHCb)

Unitarity Triangle

- Jordy Butter (Cambridge, LHCb)
- Alessandro Gaz (University of Padova, Belle II)
- Tim Gershon (Warwick, BABAR / LHCb)
- **Matthew Kenzie** (Cambridge, LHCb)
- Michele Veronesi (Iowa State, Belle II)

Charm Oscillations and CP violation

- Jolanta Brodzicka (Polish Academy of Sciences, LHCb)
- **Marco Gersabeck** (Freiburg, LHCb)
- **Alan Schwartz** (Cincinnati, Belle / Belle II)

Rare Decays

- Flavio Archilli (INFN Roma Tor Vergata, LHCb)
- Emilie Bertholet (Tel Aviv, Belle II)
- **Eli Ben-Haim** (LPNHE-Paris, BABAR / LHCb)
- Pablo Goldenzweig (Karlsruhe, Belle II)
- Justine Serrano (CPPM Marseille, Belle II)

B To Charm

- Daniel Johnson (Birmingham, LHCb)
- **Thomas Kuhr** (Ludwig-Maximilians-University, Belle II)
- Roman Mizuk (ICJLab, Belle II)
- Luka Santelj (Ljubljana, Belle II)
- Mark Whitehead (Glasgow, LHCb)

Charm Decays

- **Bai-Cian Ke** (Zhengzhou, BES-III)
- Hailong Ma (IHEP, BES-III)
- **Paras Naik** (Liverpool, LHCb)
- John Yelton (Florida, Belle / Belle II)

Semileptonic

- Concezio Bozzi (INFN Ferrara, BABAR / LHCb)
- Lu Cao (Fudan University, Belle II)
- Lucia Grillo (Glasgow University, LHCb)
- Markus Prim (Bonn, Belle II)
- **Marcello Rotondo** (INFN Frascati, BABAR / LHCb)
- **Christoph Schwanda** (Austrian Academy of Sciences, Belle II)

Tau Physics

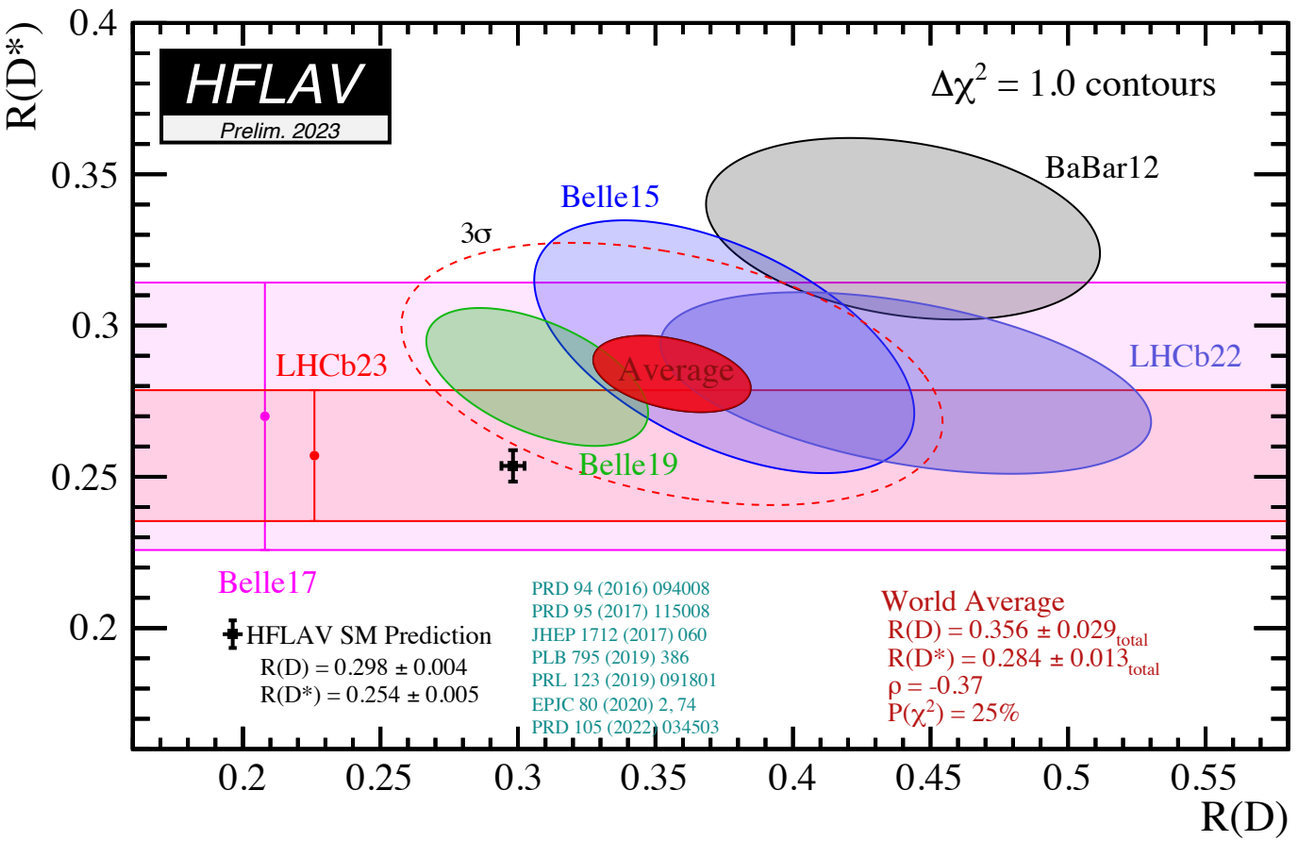
- **Swagato Banerjee** (University of Louisville, Belle-II)
- Marcin Chrząszcz (CERN, LHCb)
- Kiyoshi Hayasaka (Niigata University, Belle)
- Hisaki Hayashii (Nara Woman's University, Belle)
- **Alberto Lusiani** (Scuola Normale Superiore and INFN Pisa, BABAR, LHCb)
- Mike Roney (University of Victoria, BABAR / Belle II)
- Boris Shwartz (BINP, Belle)

The physics

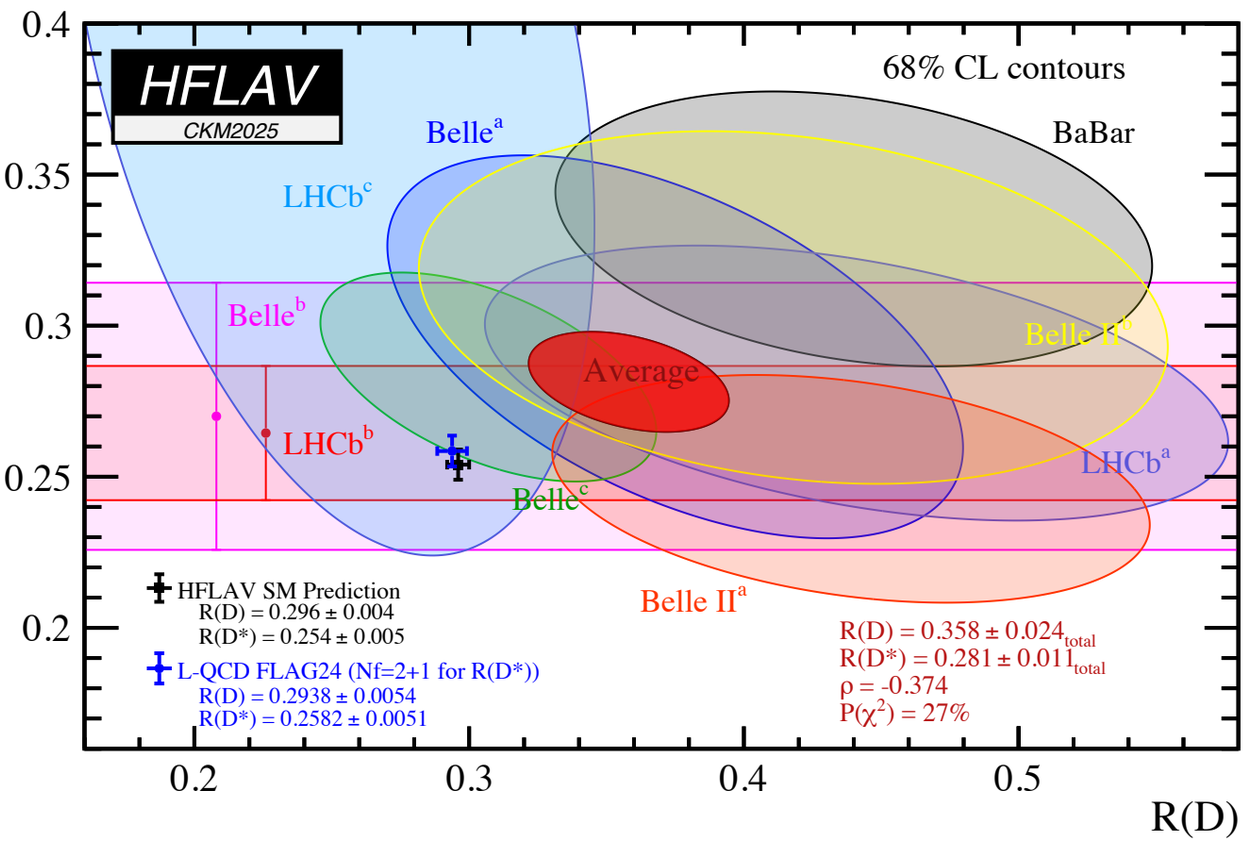
- b-hadron lifetimes and oscillation parameters
- Semi-leptonic B decays
- Rare B decays
- Unitarity triangle angles
- B decays to charm final states
- Charm CP violation and oscillations
- Charm decays
- Tau Physics

LFU in semileptonic *B* decays

2023



2025

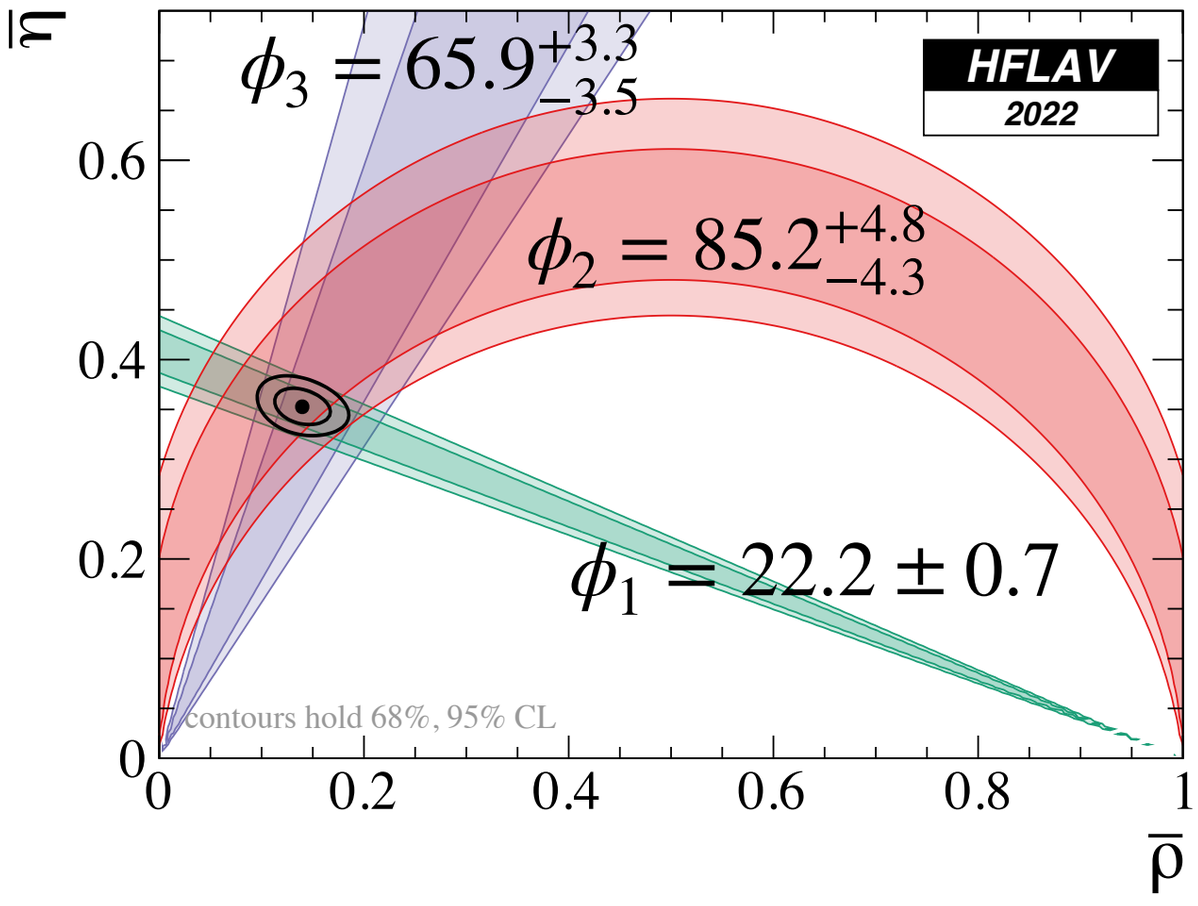


Getting more and more crowded!

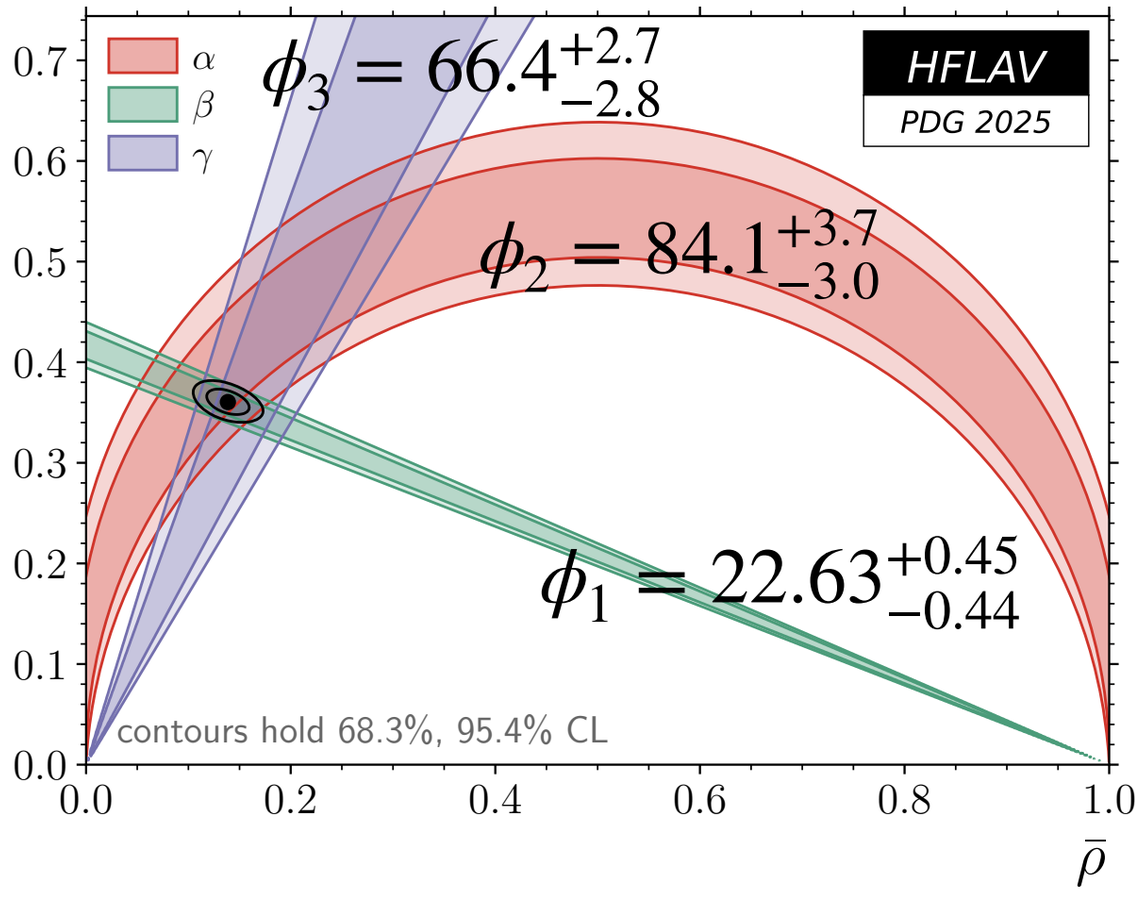
Now contours with 68% CL

UT angles

2022



2025

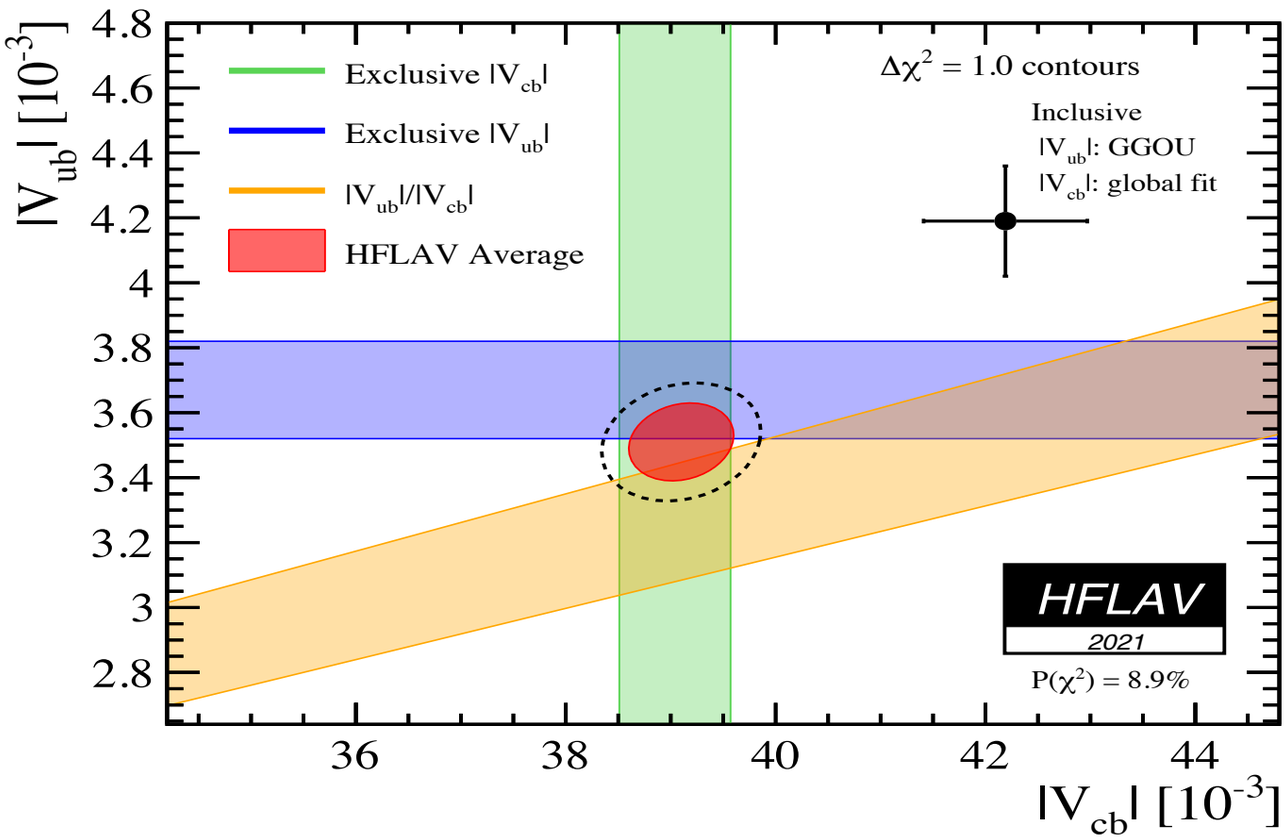


LHCb drives ϕ_3/γ and ϕ_1/β.

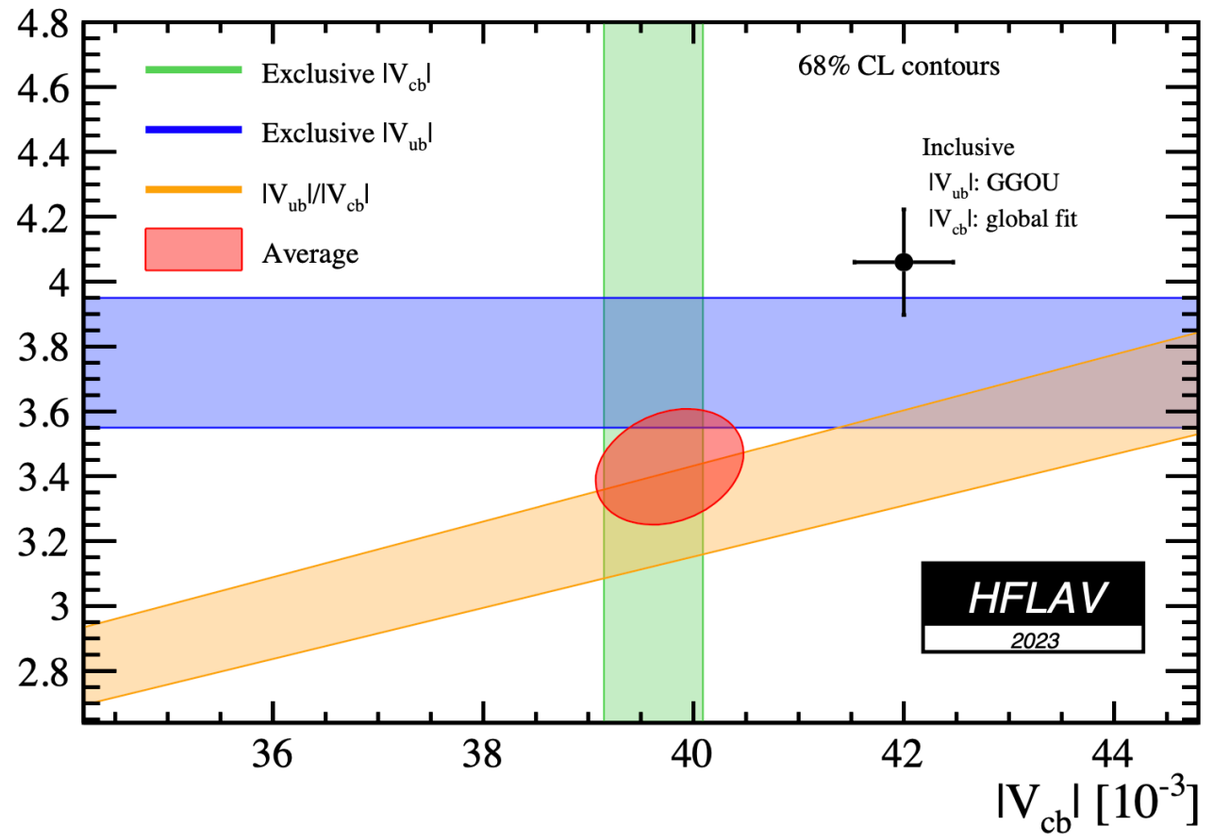
Belle II improves ϕ_2/α.

UT sides

2021



2023

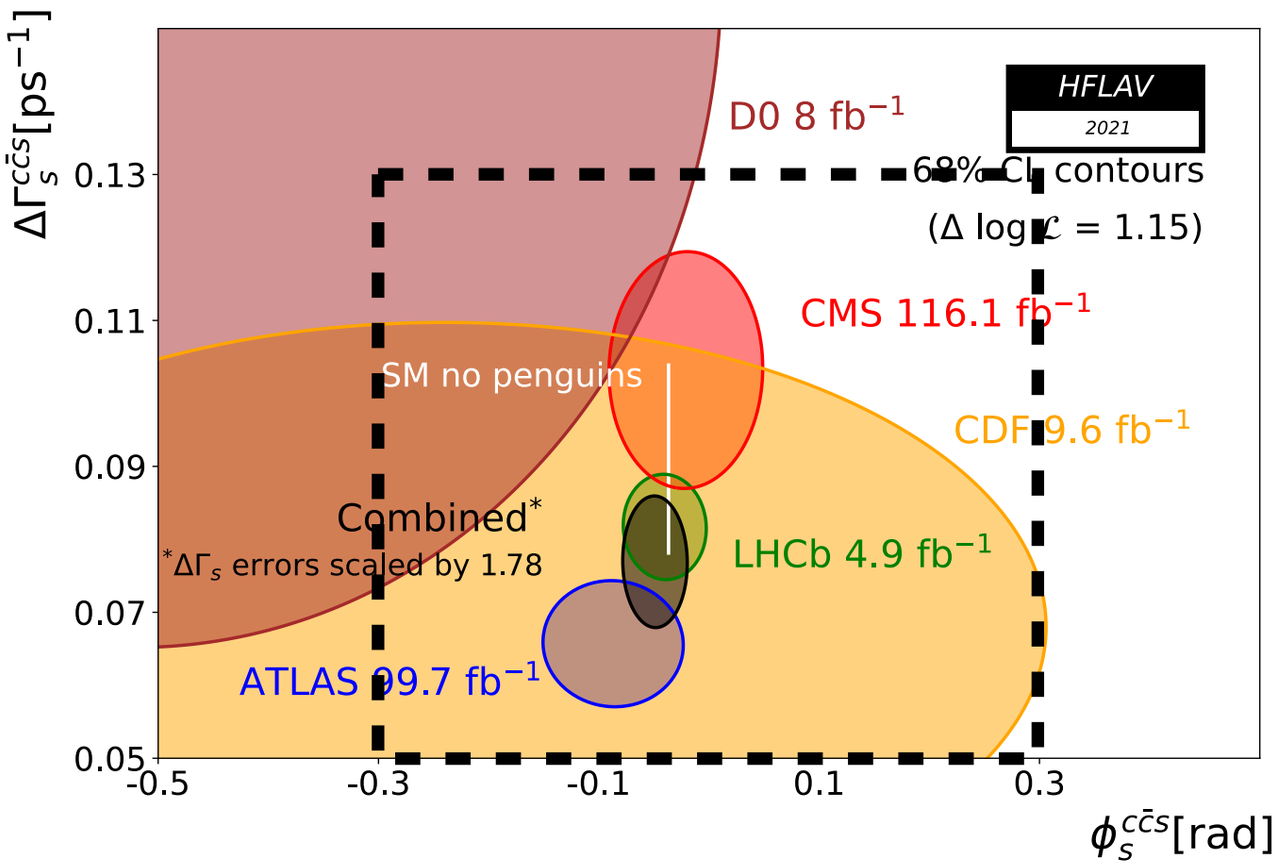


Inclusive-exclusive gap hard to close.

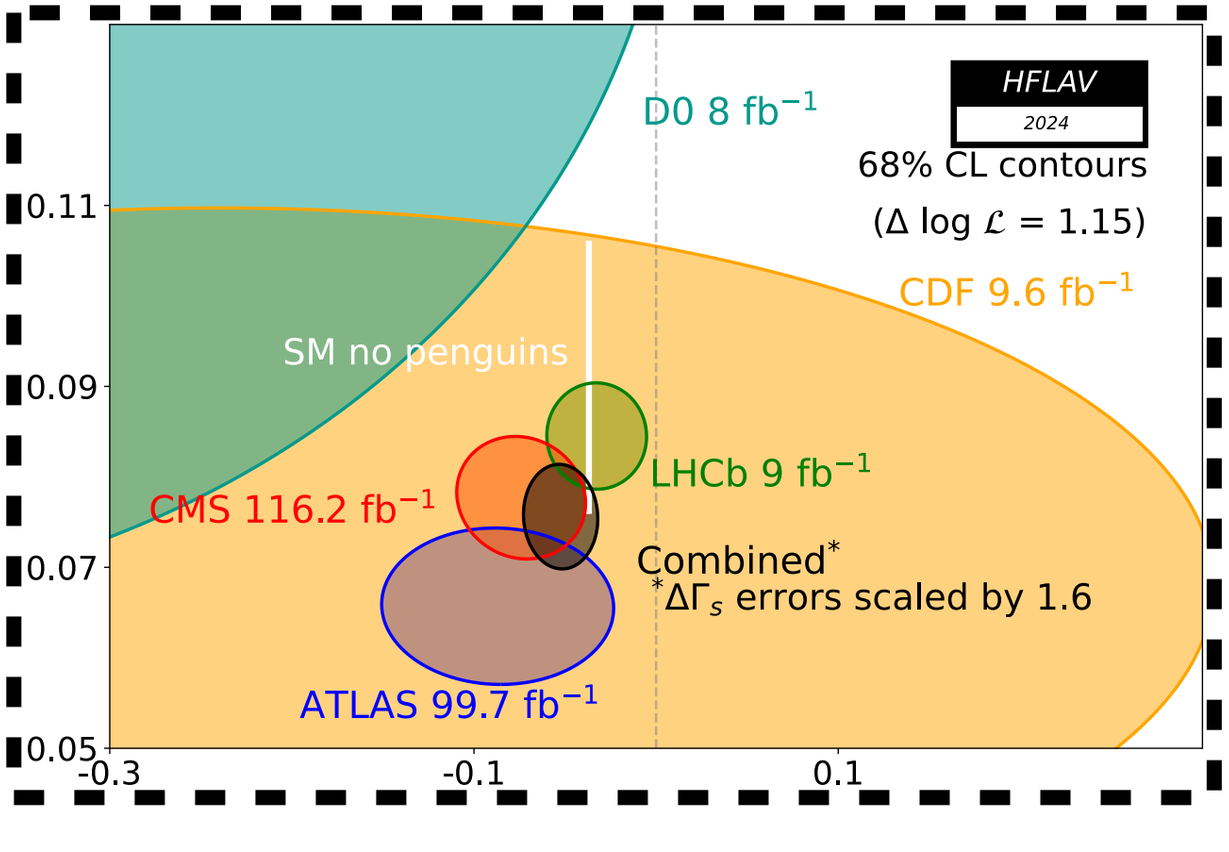
$|V_{cb}|$ puzzle main issue for high-precision SM predictions.

CPV in B_s^0 oscillations

2021



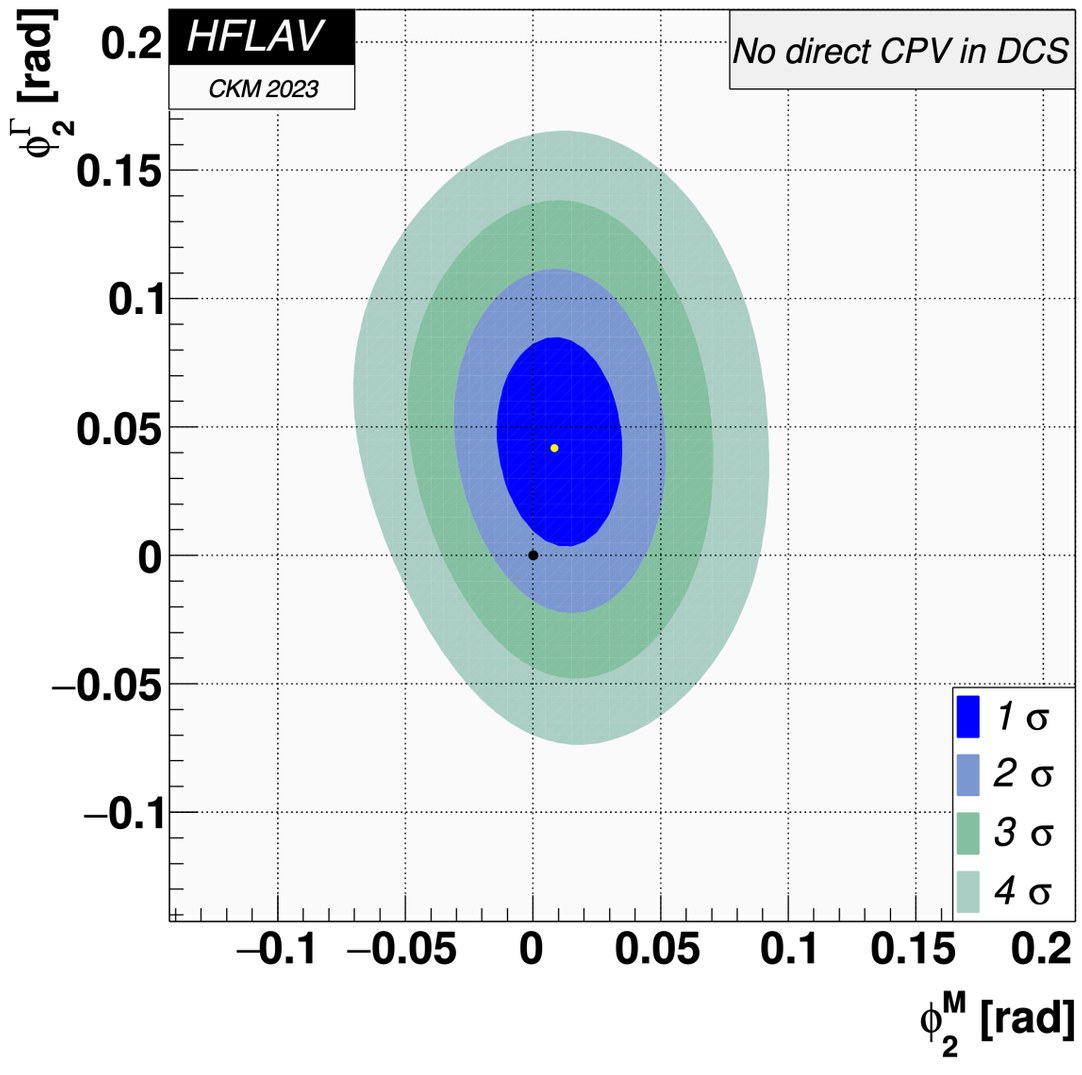
2024



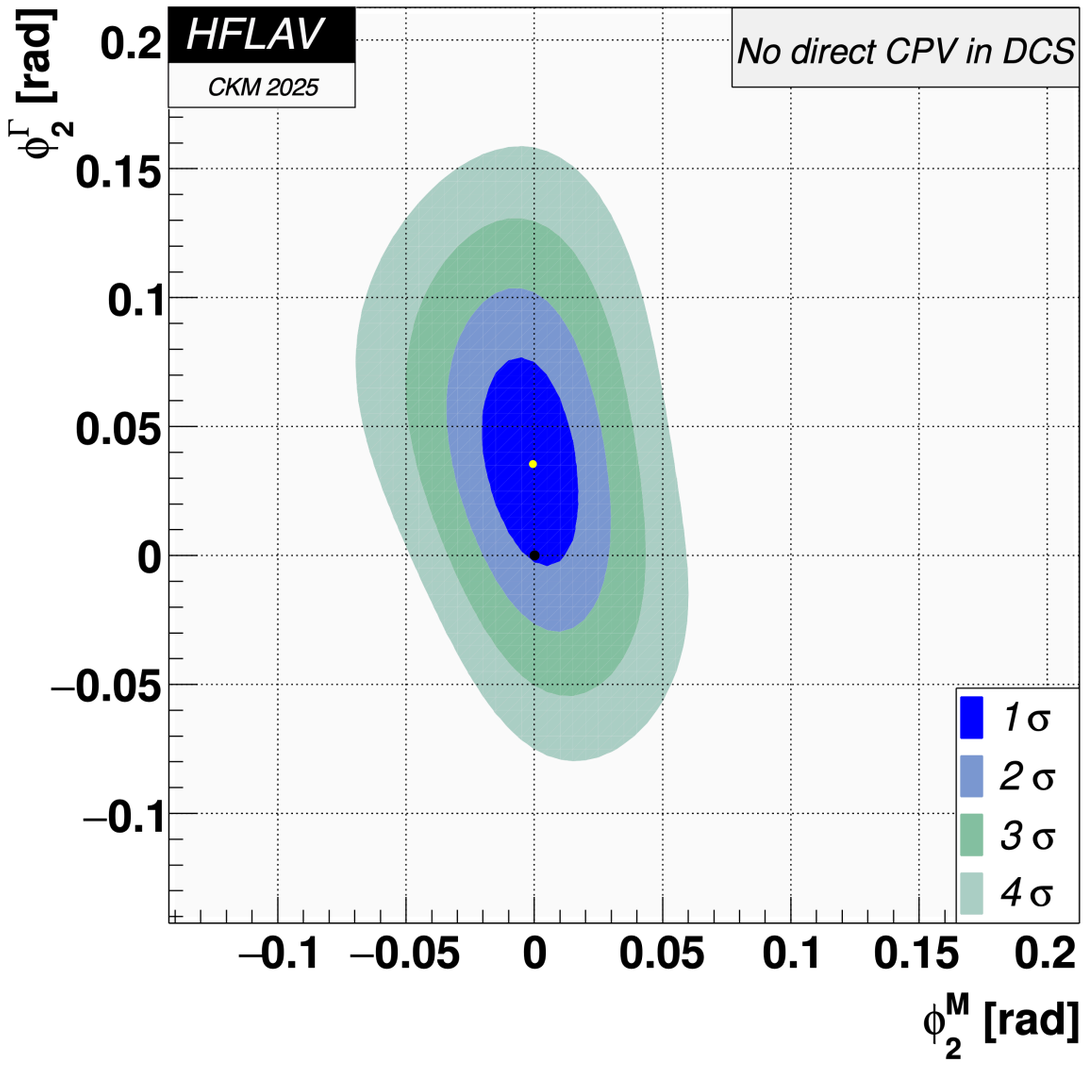
Significant contribution from GPDs

CPV in D^0 oscillations

2023



2025

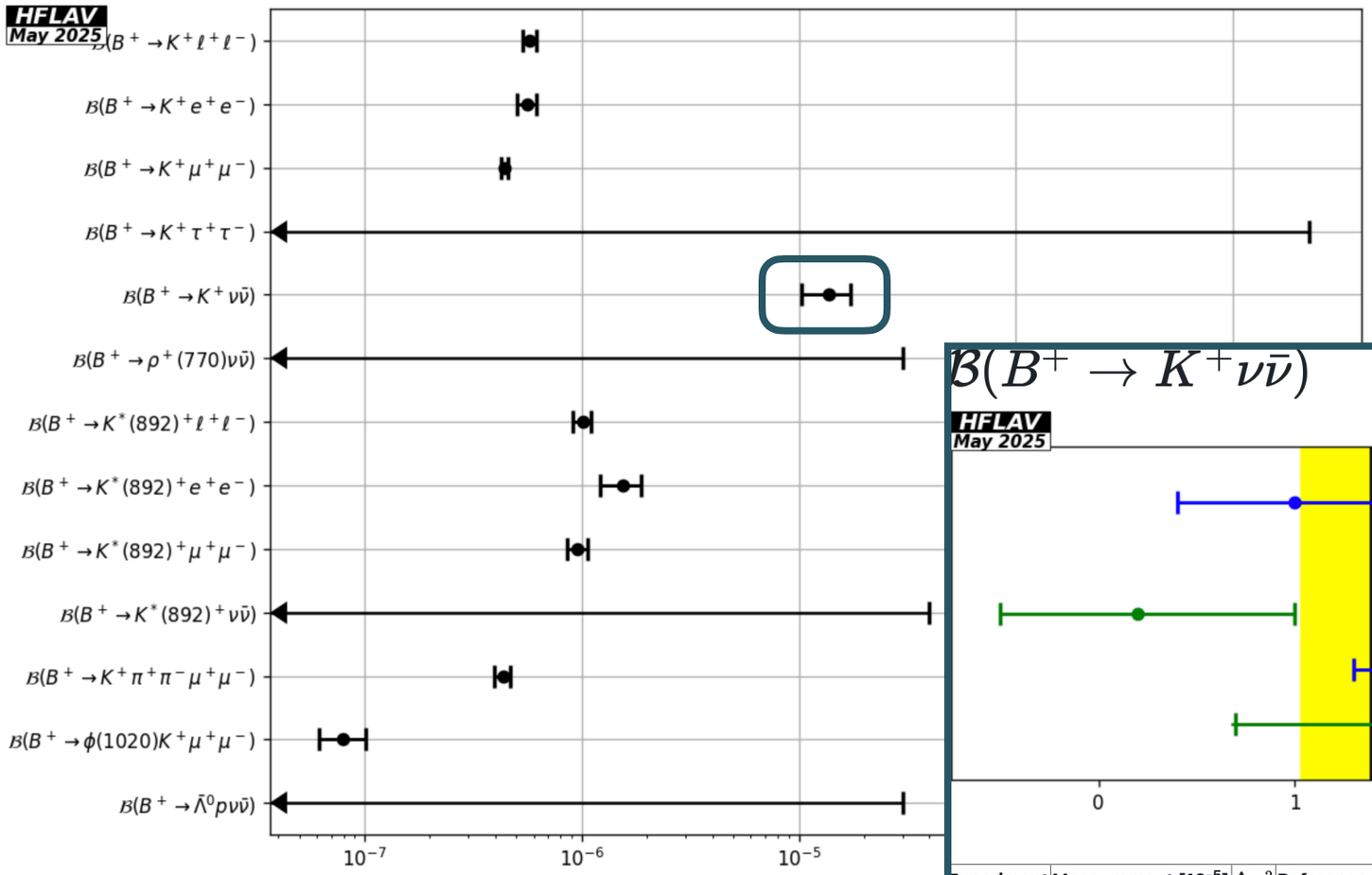


Led by single and double tagged measurements at LHCb.

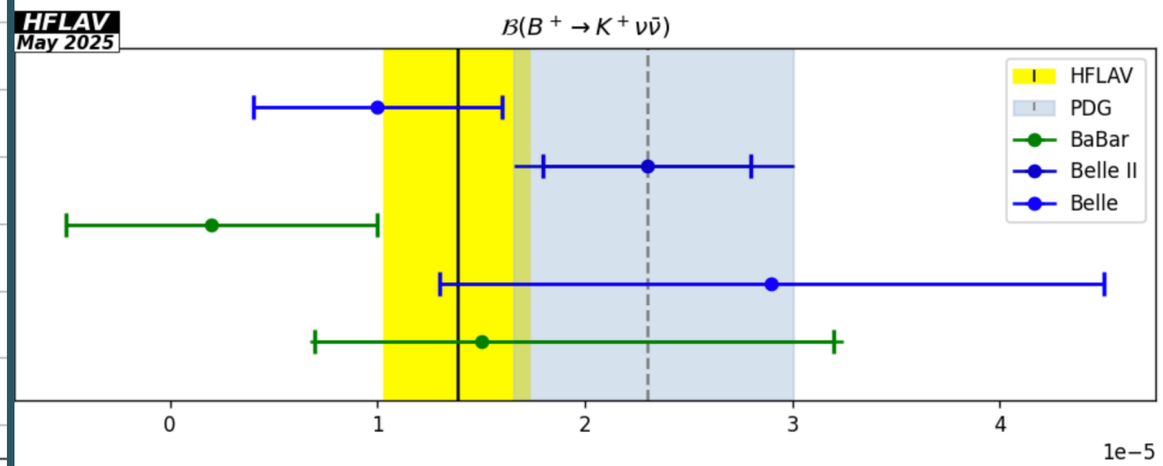
No evidence of indirect CPV.

Rare decays

Branching fractions of B^+ radiative and FCNC decays with leptons (part 5)



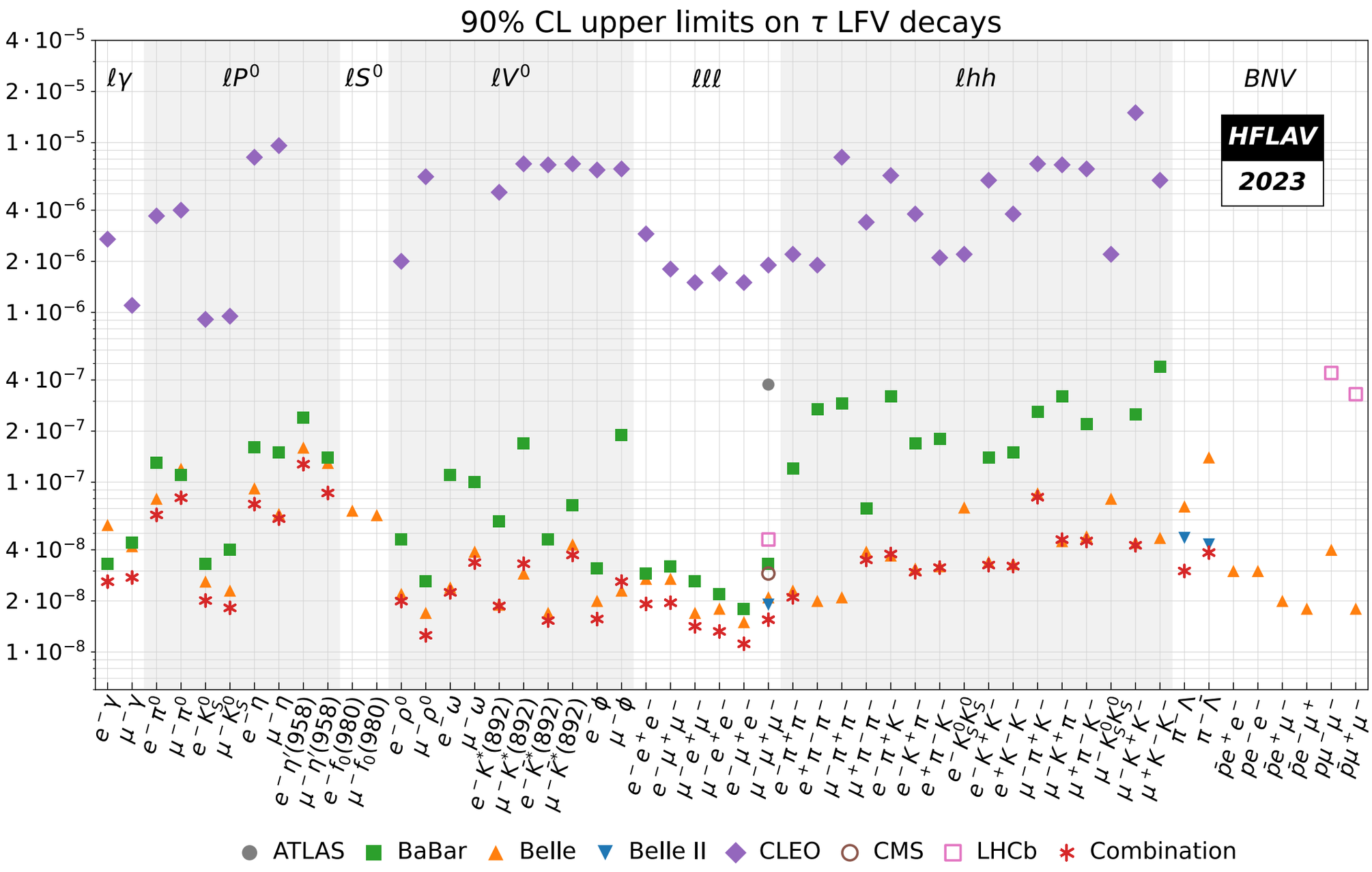
$\mathcal{B}(B^+ \to K^+\nu\bar{\nu})$



Experiment	Measurement [10^{-5}]	$\Delta\chi^2$	Reference	Comments
Average	1.38 ± 0.35	5.55	$p = 0.23$ (ndf=4)	
PDG	$2.30\ ^{+0.71}_{-0.64}$		pdgLive	
Belle	1.00 ± 0.60	0.41	Phys.Rev.D **96**,091101 (2017)	Semileptonic tag. Paper only reports UL. The value reported here is calculated in Ref.~\cite{Belle-II:2023e
Belle II	$2.3 \pm 0.5\ ^{+0.5}_{-0.4}$	2.05	Phys.Rev.D **109**,112006 (2024)	
BaBar	$0.20\ ^{+0.80}_{-0.70}$	2.19	Phys.Rev.D **82**,112002 (2010)	Semileptonic tag
Belle	2.90 ± 1.60	0.90	Phys.Rev.D **87**,111103 (2013)	Hadronic tag. Paper only reports UL. The value reported here is calculated in Ref.~\cite{Belle-II:2023esi}
BaBar	$1.50\ ^{+1.70\ +0.40}_{-0.80\ -0.20}$	0.01	Phys.Rev.D **87**,112005 (2013)	Hadronic tag.

Always report BR estimates for combinations!

LFV in tau decays



Many updates from Belle II expected!

Precision normalisation

BR(Y(4S)→*BB*) needed to get **all** *B* decay rates. Careful treatment of common isospin assumptions and current knowledge of non-*BB* decays

Measurement	Method	External parameters	Experiment
f^{+-}/f^{00}			
$1.04 \pm 0.07 \pm 0.04$	$J/\psi K^{(*)}$	$\tau(B^+)/\tau(B^0) = 1.066 \pm 0.024$	CLEO, 2001 [11]
$1.06 \pm 0.02 \pm 0.03$	$(c\bar{c})K^{(*)}$	$\tau(B^+)/\tau(B^0) = 1.086 \pm 0.017$	*BABAR*, 2005 [12]
$1.065 \pm 0.012 \pm 0.019 \pm 0.047$	$J/\psi K$	$\tau(B^+)/\tau(B^0) = 1.076 \pm 0.004$	Belle, 2023 [13]
$1.058 \pm 0.084 \pm 0.136$	$D^*\ell\nu$	$\tau(B^+)/\tau(B^0) = 1.074 \pm 0.028$	CLEO, 2002 [14]
$1.01 \pm 0.03 \pm 0.09$	Dilepton events	$\tau(B^+)/\tau(B^0) = 1.083 \pm 0.017$ $\tau(B^0) = (1.542 \pm 0.016)$ ps	Belle, 2003 [15]
f^{00}			
$0.487 \pm 0.010 \pm 0.008$			*BABAR*, 2005 [16]
$f_{\not B}$			
$-0.0011 \pm 0.0143 \pm 0.0107$	Semileptonic decays		CLEO, 1996 [17]
$\geq 0.00264 \pm 0.00021$	Sum of known channels		*BABAR*, Belle [18–21]

See Roman's talk at 18/08 PGM

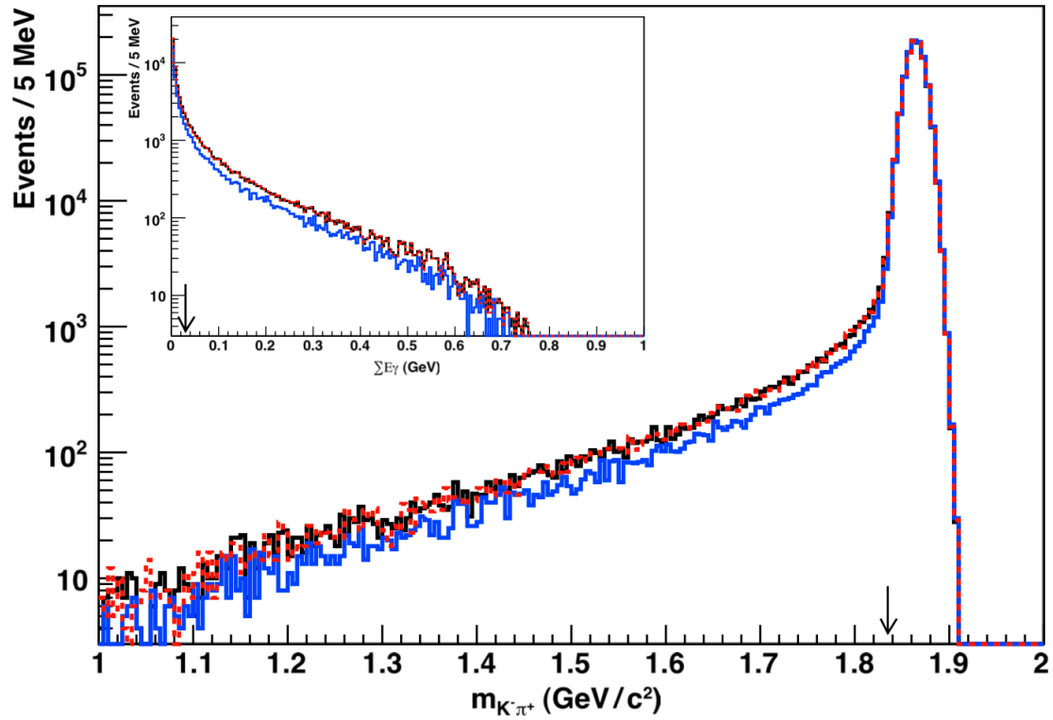
$$f^{00} = 0.4861^{+0.0074}_{-0.0080}\,, \quad f^{+-} = 0.5113^{+0.0073}_{-0.0108}\,, \quad f_{\not B} = 0.00264^{+0.0125}_{-0.0002}\,, \quad \frac{f^{+-}}{f^{00}} = 1.052 \pm 0.031$$

Impact all *B* branching fractions, $|V_{cb}|$, ϕ_2/α, …

High-precision normalisation

BR($D^0 \to h^+h'^-$) reaching 1% precision require careful treatment of subtle effects such as final-state radiation.

Measurements spanning from ’90 till nowadays use different PHOTOS versions: inconsistent impact on efficiencies.



Modes fit	Description	$\mathcal{B}(D^0 \to K^-\pi^+)$ (%)	χ^2/(deg. of freedom)
$K^-\pi^+$	PDG 2023 [302] equivalent	$3.910 \pm 0.006 \pm 0.033$	$5.1/(9-1) = 0.64$
$K^-\pi^+$	drop Ref. [1332]	$3.913 \pm 0.006 \pm 0.033$	$5.1/(8-1) = 0.73$
$K^-\pi^+$	add FSR updates	$3.948 \pm 0.006 \pm 0.032 \pm 0.019$	$3.5/(8-1) = 0.50$
$K^-\pi^+$	add FSR correlations	$3.949 \pm 0.006 \pm 0.032 \pm 0.033$	$3.7/(8-1) = 0.53$
all	add CLEO-c, CDF, and FOCUS h^+h^-	$3.956 \pm 0.006 \pm 0.032 \pm 0.033$	$11.1/(14-3) = 1.01$
all	add BESIII h^+h^-	$3.999 \pm 0.006 \pm 0.031 \pm 0.032$	$36.0/(16-3) = 2.77$

1% shift comparable to current precision. Impact many *B* rates,, exclusive SL decays (and the gap), $|V_{cb}|$, f_s/f_d, …

PDG versus HFLAV

- Is HFLAV just duplicating PDG work?
  - **Many PDG averages are in fact provided by HFLAV**
- In depth reviews often depends on HFLAV analysis.
- Many branching fraction fits compared and multiple issues identified and fixed on both sides
- General practical differences b/w PGD and HFLAV
  - Preliminary results: **HFLAV does** include them, **PDG does not**
  - Inflating uncertainties (for low *p*-value):
    PDG does, **HFLAV (generally) does not**

Multiple HFLAV results in PDG

Some examples…

B^0 MEAN LIFE

See $B^{\pm}/B^0/B_s^0/b$-baryon ADMIXTURE section for data on B-hadron me

VALUE (10^{-12} s)	*EVTS*	
$(1517 \pm 4) \times 10^{-3}$	**OUR EVALUATION**	(Produced by HFLAV)

$\Delta m_{B^0} = m_{B^0_H} - m_{B^0_L}$

Δm_{B^0} is a measure of 2π times the $B^0 - \overline{B}^0$ oscillation frequenc

"OUR EVALUATION" is an average using rescaled values of the c
and includes Δm_d calculated from χ_d measured at $\Upsilon(4S)$.

VALUE (10^{12} $\hbar$ s^{-1})		
0.5069 ± 0.0019	**OUR EVALUATION**	(Produced by HFLAV)

$\Gamma(\tau^- \to \text{particle}^- \geq 0 \text{ neutrals } \geq 0 K^0 \nu_\tau \text{ (``1-prong'')})/\Gamma_{\text{total}}$

$\Gamma_1/\Gamma = (\Gamma_3 + \Gamma_5 + \Gamma_9 + \Gamma_{10} + \Gamma_{14} + \Gamma_{16} + \Gamma_{20} + \Gamma_{23} + \Gamma_{27} + \Gamma_{28} + \Gamma_{30} + \Gamma$
$+ 0.71946\Gamma_{152} + 0.71946\Gamma_{154} + 0.71946\Gamma_{156} + 0.33641\Gamma_{170} + 0.083$

VALUE (%)	*EVTS*	*DOC*
85.24 ± 0.06	**OUR FIT**	(Produced by HFLAV)

$\sin(2\beta)$

For a discussion of C

VALUE		
0.710 ± 0.011	**OUR EVALUATION**	(Produced by HFLAV)

$|V_{cb}| \times F(1)$ (from $B^0 \to D^{*-} \ell^+ \nu$)

VALUE (10^{-2})	*DO*	
3.522 ± 0.037	**OUR EVALUATION**	(Produced by HFLAV)

Multiple HFLAV results in PDG

Table 76.2: $|V_{ub}|$ (in units of 10^{-5}) from inclusive $\bar{B} \to X_u \ell \bar{\nu}_\ell$ measurements. The first uncertainty on $|V_{ub}|$ is experimental, while the second includes both theoretical and HQE parameter uncertainties. The values are generally listed in order of increasing kinematic acceptance, f_u (0.19 to 0.90), except for the BABAR E_e >0.8 GeV measurement; th… based on recoil methods. The Belle 2023 measurement is not ye…

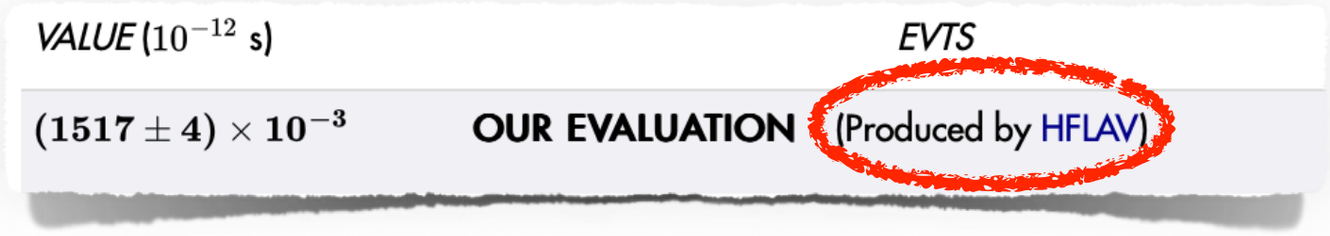
Ref.	cut (GeV)	BLNP	GG…
CLEO [181]	$E_e > 2.1$	$422 \pm 49 \,^{+29}_{-34}$	423 ±
BABAR [184]	$E_e - q^2$	$471 \pm 32 \,^{+33}_{-38}$	not a…
Belle [182]	$E_e > 1.9$	$493 \pm 46 \,^{+26}_{-29}$	495 ±
BABAR [183]	$E_e > 0.8$	$441 \pm 12 \,^{+27}_{-27}$	396 ±
BABAR [186]	$^{q^2>8}_{m_X<1.7}$	$432 \pm 23 \,^{+26}_{-28}$	433 ±
BABAR [186]	$P_+ < 0.66$	$409 \pm 25 \,^{+25}_{-25}$	425 ±
BABAR [186]	$m_X < 1.7$	$403 \pm 22 \,^{+22}_{-22}$	410 ±
BABAR [186]	$E_\ell > 1.3$	$433 \pm 24 \,^{+19}_{-21}$	444 ±
Belle [173]	$E_\ell > 1$	$405 \pm 23 \,^{+18}_{-20}$	415 ±
Belle [176]	$E_\ell > 1$	$415 \pm 24 \,^{+18}_{-20}$	425 ±
HFLAV [6]	Combination	$428 \pm 13 \,^{+20}_{-21}$	419 ±

normalized to $D^0 \to K^-\pi^+$ decays, and results from HFLAV [15] obtained from a global fit to all relevant data that allows for both mixing and CP violation (see Section 70.7). The experiments typically perform a single fit for parameters R_D, x'^2, and y'; results for x'^2 and y' are listed in Table 70.3. Allowing for CP violation, the experiments measure parameters (R_D^+, x'^2_+, y'_+) and (R_D^-, x'^2_-, y'_-) [or equivalently (R_D, A_D) instead of (R_D^+, R_D^-)] by separately fitting the $D^0 \to K^+\pi^-$ and $\overline{D}^0 \to K^-\pi^+$ event samples.

Table 70.2: Results for R, R_D, and A_D as measured using $D^0 \to K^\pm\pi^\mp$ decays. When a single uncertainty is listed, that corresponds to statistical and systematic uncertainties combined. The measurements with an asterisk (*) have been superseded and thus are not included in the HFLAV global fit (Section 70.7). The measurements with a dagger (†) are not included in the HFLAV global fit due to much poorer precision.

Year	Experiment	$R\,(\times 10^{-3})$	$R_D\,(\times 10^{-3})$	$A_D\,(\%)$
2018	LHCb (5.0 fb^{-1} D^* tag) [16]	—	3.454±0.031	−0.01±0.91
2017	LHCb (3.0 fb^{-1} B+D^* double tag) [17]	—	3.48±0.10	−3.15±3.31
2014	Belle (976 fb^{-1}) [18]	3.86±0.06	3.53±0.13	—
2013	CDF (9.6 fb^{-1}) [19]	4.30±0.05	3.51±0.35	—
2007	BABAR (384 fb^{-1}) [20]	3.53±0.08±0.04	3.03±0.16±0.10	−2.1±5.2±1.5
	HFLAV Fit Result [15]		**3.434 ± 0.019**	**−0.70 ± 0.36**
2013b*	LHCb (3.0 fb^{-1} D^* tag) [21]	—	3.568±0.066	−0.7±1.9
2013a*	LHCb (1.0 fb^{-1}) [22]	4.25±0.04	3.52±0.15	—
2008*	CDF (1.5 fb^{-1}) [23]	4.15±0.10	3.04±0.55	—
2006*	Belle (400 fb^{-1}) [24]	3.77±0.08±0.05	3.64±0.18	2.3±4.7
2005†	FOCUS (234 evts) [25]	$4.29\,^{+0.63}_{-0.61}$±0.27	$5.17\,^{+1.47}_{-1.58}$±0.76	$13\,^{+33}_{-25}$±10
2000†	CLEO (9.0 fb^{-1}) [26]	$3.32\,^{+0.63}_{-0.65}$±0.40	4.8±1.2±0.4	$-1\,^{+16}_{-17}$±1
1998†	E791 (5643 evts) [27]	$6.8\,^{+3.4}_{-3.3}$±0.7	—	—

Links in PDG to HFLAV



- Often many clicks away from a web page that gives the background to the result.

- **Sometimes nowhere to find the information about which papers used, which theory parameters, etc.**

- **Scientifically very unsatisfactory** that specific HFLAV results are often hard to find full and accurate documentation for.

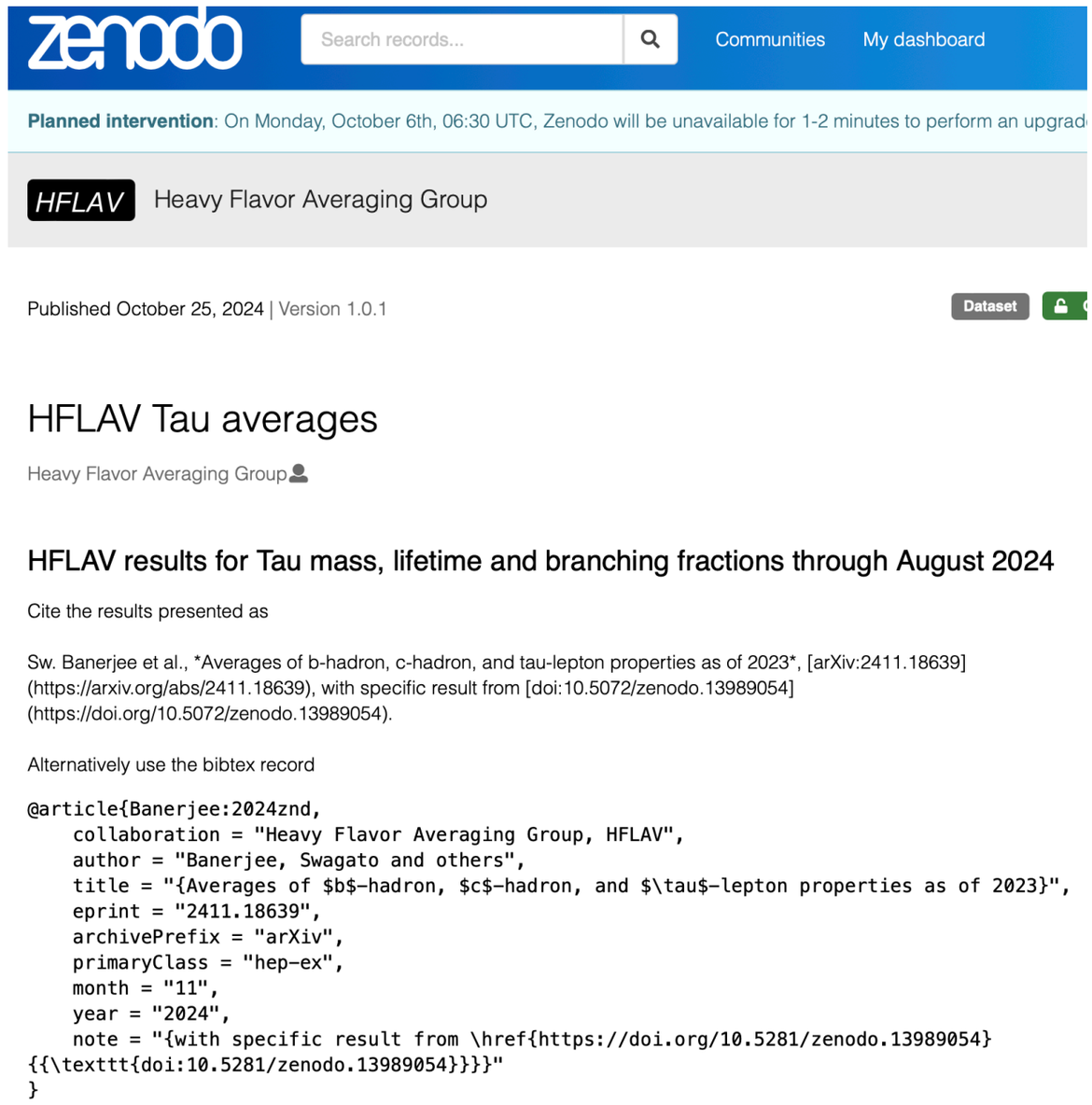
  - PDG has made huge improvements in this area

Making us **FAIR**

- The principles we should aim for our results:
  - **F**indable ⇒ assign *doi*
  - **A**ccessible ⇒ open long-term repository (Zenodo)
  - **I**nteroperable ⇒ JSON files (matching PDG standard)
  - **R**eusable ⇒ improve documentation and software

A first example

- Tau results saved in Zenodo with a permanent doi.
- Specific results cited as:
  *"Sw. Banerjee et al., Averages of b-hadron, c-hadron, and tau-lepton properties as of 2023, [arXiv:2411.18639], **with specific result from doi:10.5282/zenodo.13989054**."*
- No more generic
  "… and updates from webpage"
- Have also permanent information on all inputs, with references to cite.



Status and work ahead

- Continuous updates on website — www.cern.ch/hflav
- Work on FAIR principles, targeting to be fully in place for next spring/summer.
- Improve documentation (webpage) as well in parallel
- Talk/write to us for any comment, suggestion, complaint…

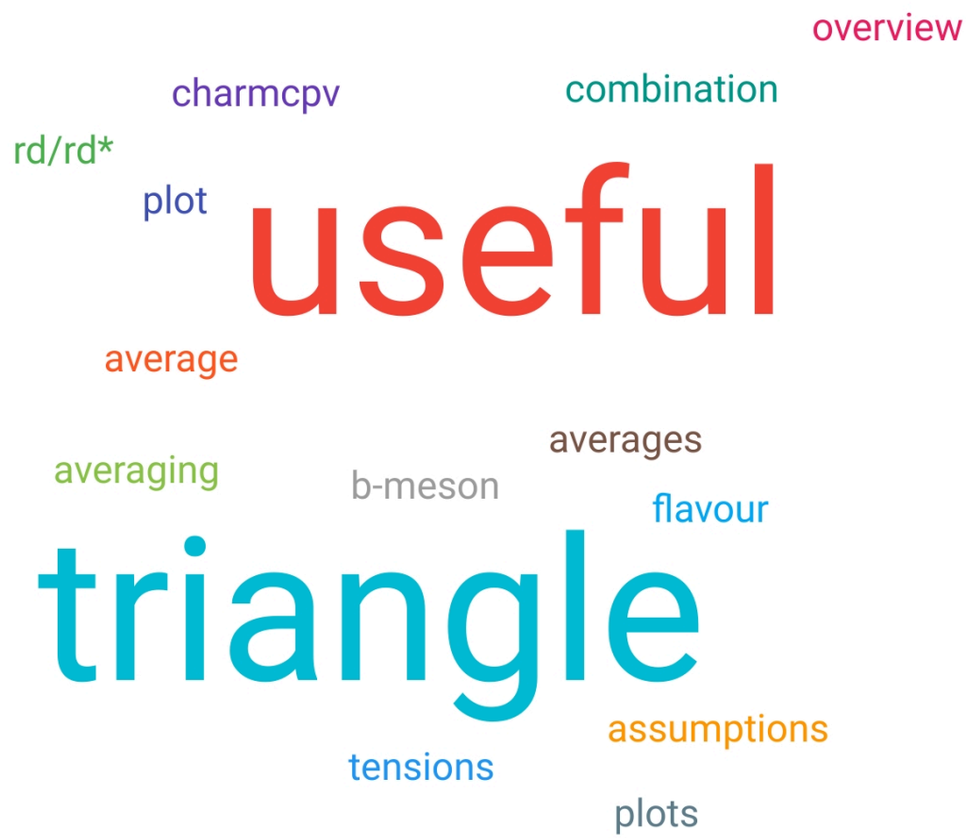
What word comes to mind?

Result:

Backup

HFLAV

What word comes to mind?



From the 2025 CKM workshop few weeks ago