Heavy Flavor Averaging Group Methodology and Latest Results

HFLAV 2021

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

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Averaging Methodology

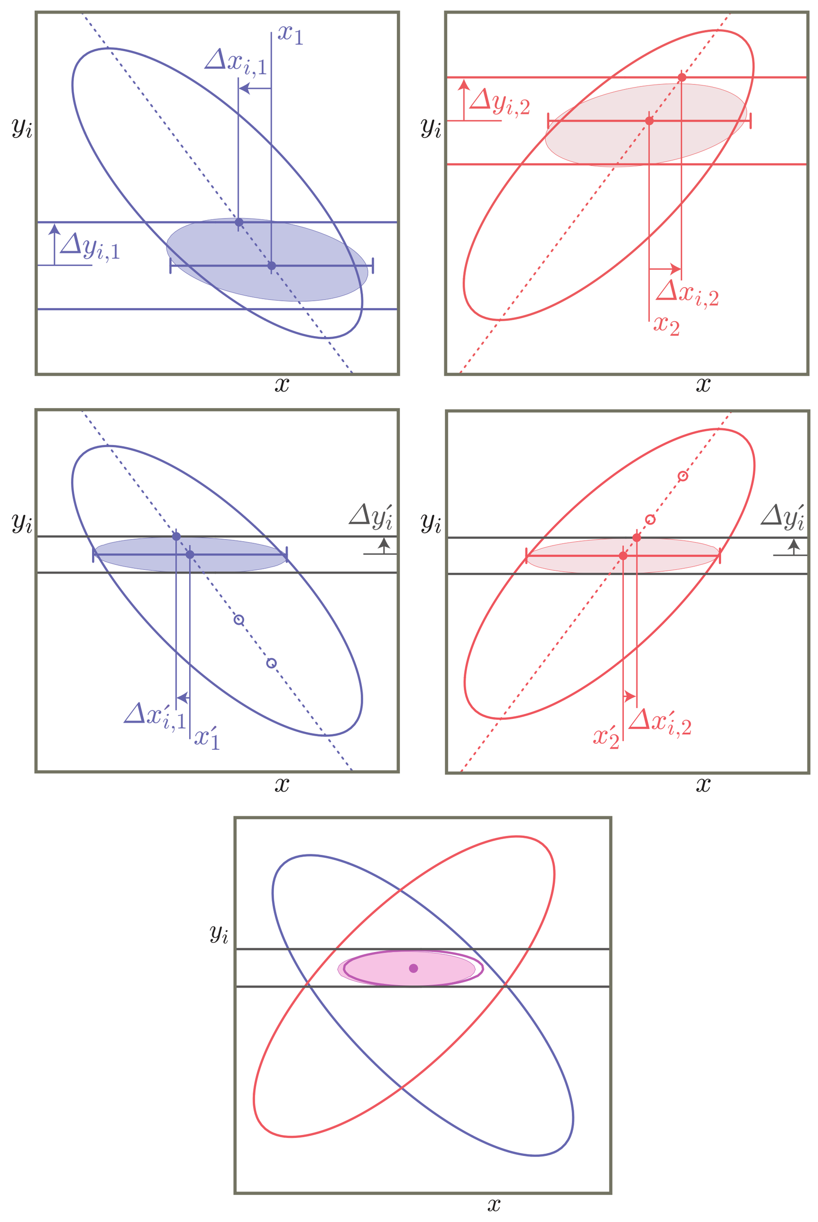
Method

- We focus on the problem of combining measurements obtained with different assumptions about external ("nuisance") parameters and the correlation of systematic uncertainties across them.
- We define the χ^2 statistic for the average, where we consider cases that the paramter of interest is not measured directly, but as a quantity that is a function of (multiple) observables.

$$\chi^2(\vec{p}) = \sum_i^N (\vec{f}_i(\vec{p}) - \vec{x}_i)^T V_i^{-1} (\vec{f}_i(\vec{p}) - \vec{x}_i)$$

Treatment of correlated systematic uncertainties

- Knowledge of external (nuisance) parameters often improve after publication, and can be easily incorporated when the unconstrained Likelihoods are provided.
- If they are not provided, we adjust the central values and correlated systematic uncertainties linearly for each measurement and each external parameter and combine the adjusted measurements.



Treatment of unknown correlations

- We choose the most conservative approach when dealing with unknown correlations between measurements: Unknown correlations are chosen so that the uncertainty on the parameter of interest is maximized.

$$\sigma^2_{\hat{x}(i,j)} = \frac{\sigma_i^2\sigma_j^2(1-\rho_{i,j}^2)}{\sigma_i^2+\sigma_j^2-2\rho_{ij}\sigma_i\sigma_j} \qquad \rho_{i,j} = \min(\frac{\sigma_i}{\sigma_j}, \frac{\sigma_j}{\sigma_i})$$

Treatment of asymmetric uncertainties

- Example: The uncertainty depends on the measured parameter.
- Biases from ignoring this can be minimized modifying the χ^2:

$$\chi^2(x) = \sum_k^N \frac{(x_k - x)^2}{\sigma_k^2(\hat{x})}$$

- Here the uncertainty includes the dependence on the measured value.

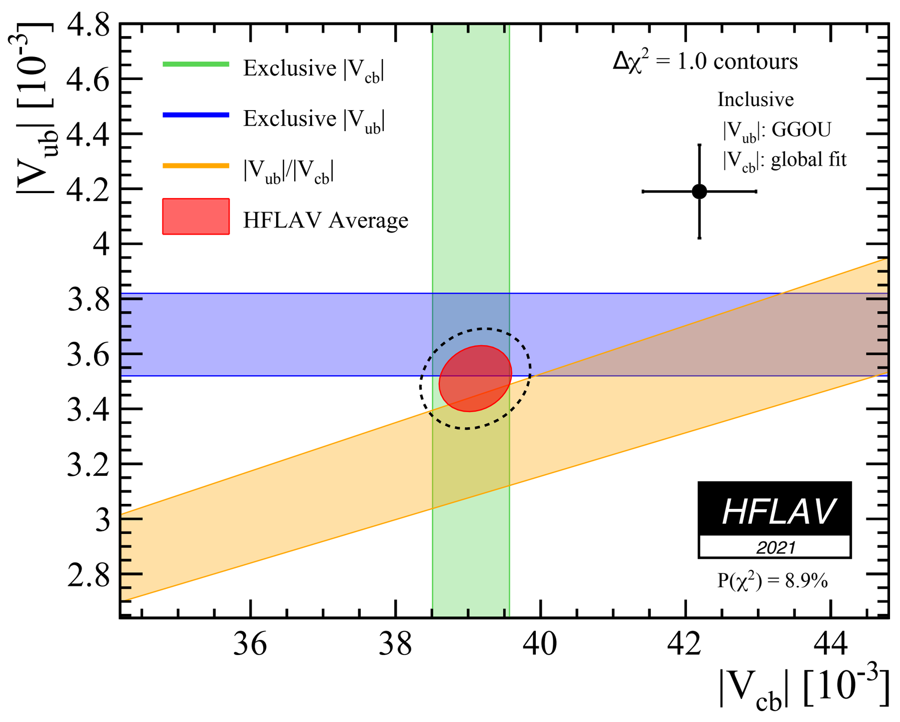
Semileptonic $b \to c/u \ell \nu_\ell$ Decays

Combined extraction of $|V_{ub}|$ and $|V_{cb}|$

- Includes measured ratios of $|V_{ub}|/|V_{cb}|$ and exclusive $|V_{ub}|$ and $|V_{cb}|$ determinations.

$|V_{ub}| = (3.51 \pm 0.12) \times 10^{-3}$
$|V_{cb}| = (39.10 \pm 0.50) \times 10^{-3}$
$\rho = 0.175$

- The average exhibits a tension of 3.3σ with the inclusive determinations of $|V_{ub}|^{GGOU}$ and $|V_{cb}|$ each.

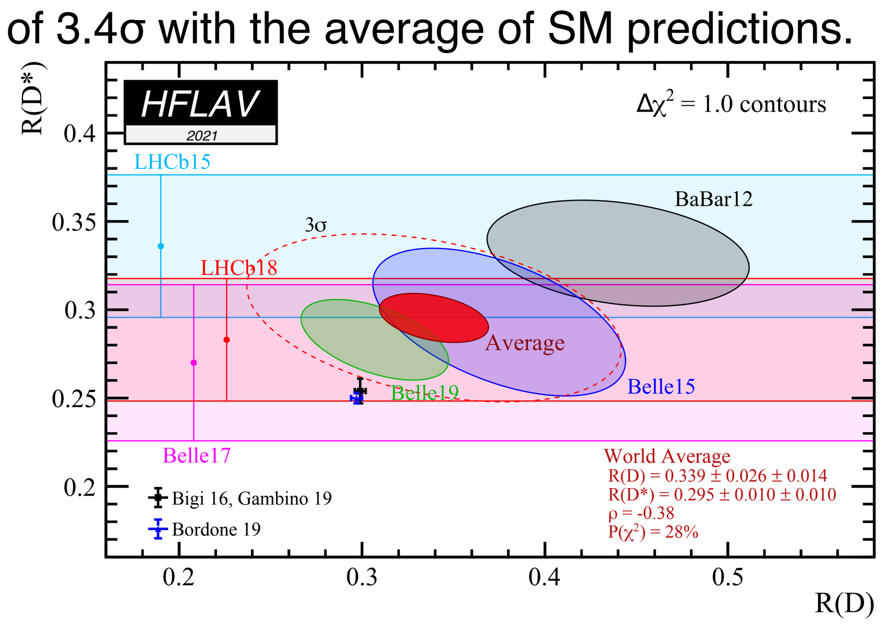


$B \to D^{(*)}\tau\nu_\tau$ decays

- Test of lepton flavor universality of the SM.
- Experiments measure the ratio of tauonic to leptonic final states.
- The SM predictions for the ratios are independent of $|V_{cb}|$ and uncertainties from the hadronic form factors cancel to a certain degree.

$R(D) = 0.295 \pm 0.010 \pm 0.010$
$R(D^*) = 0.339 \pm 0.026 \pm 0.014$
$\rho = -0.38$

- The experimental average exhibits a tension of 3.4σ with the average of SM predictions.



Unitarity Triangle Angles

Constraints on the CKM parameters $\bar{\eta}$ and $\bar{\rho}$ from the angles

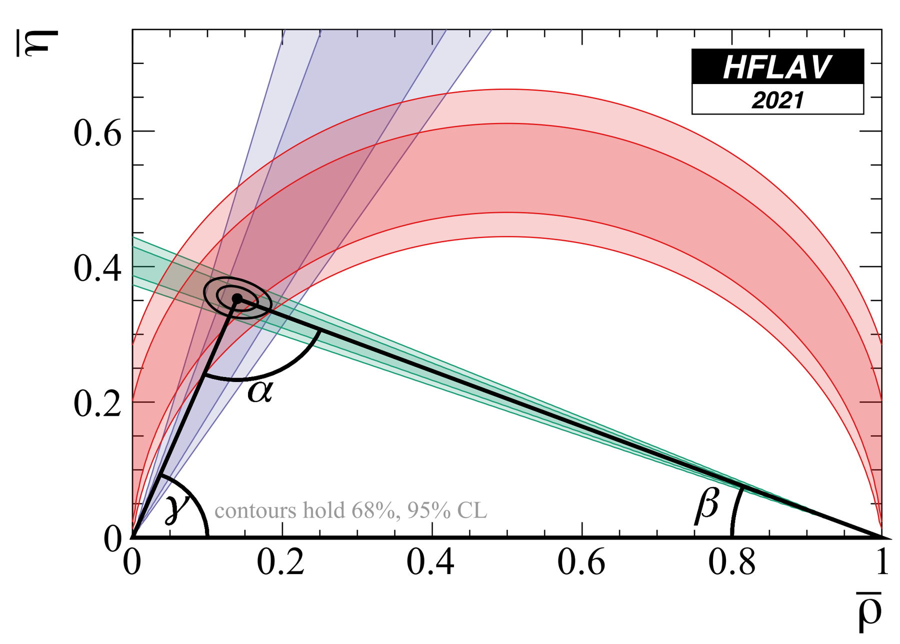
- We obtain averages for

$\beta = \phi_1 = (22.2 \pm 0.7)°$ or $(67.8 \pm 0.7)°$
$\alpha = \phi_2 = (85.2\ ^{+4.8}_{-4.3})°$
$\gamma = \phi_3 = (66.2\ ^{+3.4}_{-3.6})°$

and use the relations

$$\tan\gamma = \bar{\eta}/\bar{\rho}$$
$$\tan\beta = \bar{\eta}/(1-\bar{\rho})$$
$$\alpha = \tan^{-1}(\bar{\rho}/\bar{\eta}) + \tan^{-1}((1-\bar{\rho})/\bar{\eta})$$

to determine $\bar{\eta}$ and $\bar{\rho}$.



$\bar{\rho} = 0.140 \pm 0.018$
$\bar{\eta} = 0.353 \pm 0.012$
$\rho = -0.287$

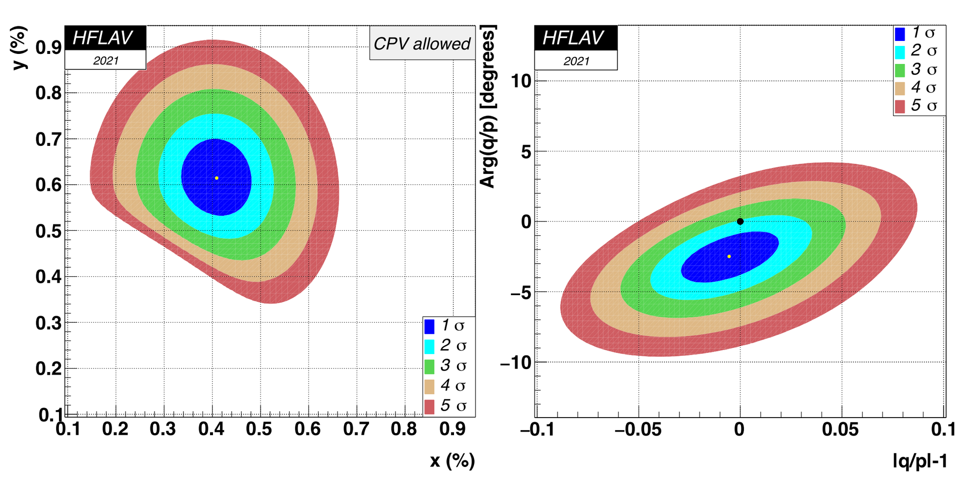
- The overlap of the constraints demonstrates agreement with the unitarity of the CKM matrix as predicted by the Standard Model.

Charm CP Violation and Oscillations

D^0-$\bar{D}^0$ mixing and CP Violation

- Combined χ^2 fit of 61 observables, extracting 10 parameters of interest.
- Different fit scenarios studied: **1.** assuming CP conservation, **2.** no weak phases in D decays, **3.** no weak phases in D decays and including theory parameters, **4.** allowing full CP violation.
- Conclusions:

$x = y = 0$ (no-mixing) excluded at >11.5σ
y_{CP} positive → CP-even state short-lived
x_{CP} positive → CP-even state heavier
No evidence $|q/p| \neq 1$ or $\phi \neq 0$.

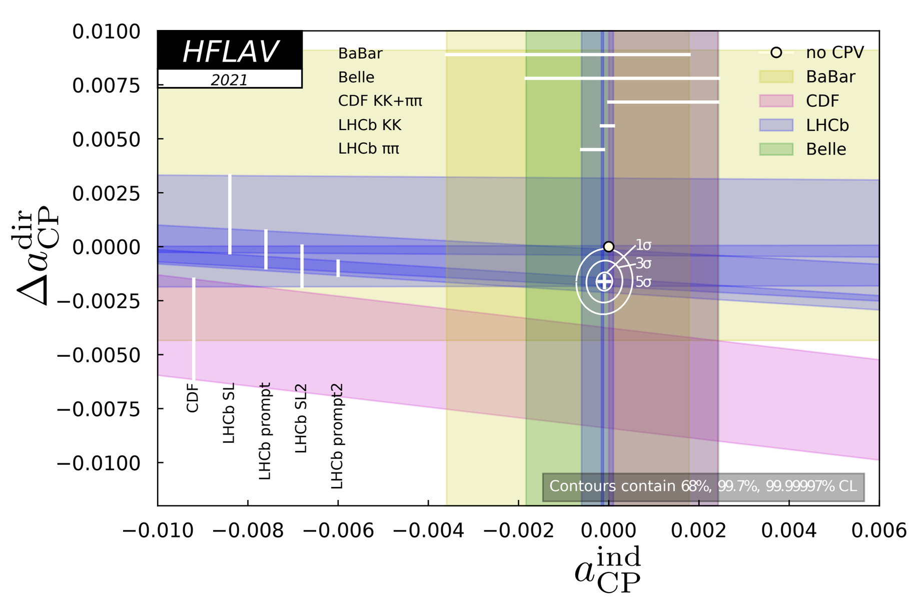


Interplay between direct and indirect CP violation

- CP asymmetry measurements in D^0 decays have contributions from direct and indirect $\not{CP}$.
- The contribution of indirect $\not{CP}$ depends on the decay-time distribution of the data.
- We perform a χ^2 fit to disentangle both contributions.

$a^{ind}_{CP} = (-0.010 \pm 0.012)\%$
$\Delta a^{dir}_{CP} = (-0.161 \pm 0.028)\%$

- No-CP violation hypothesis rejected with 5.4σ.



Charm Decays

$|V_{cd}|$ and $|V_{cs}|$

- Obtained from leptonic $D^+ \to \mu^+\nu$ and $D^+_s \to \mu^+\nu/\tau^+\nu$ decays.
- Lattice QCD calculations for the decay constants have improved, reducing the theoretical uncertainty <15%.

$|V_{cd}| = 0.2181 \pm 0.0049 \pm 0.0007$
$|V_{cs}| = 0.9839 \pm 0.0115 \pm 0.0020$
(stat.) (LQCD)

- The direct extractions of the CKM matrix elements agree with the indirect determinations via the unitarity constraint.

And More!

- The HFLAV report is over 500 pages long and provides much more detail and many more results than presented on this poster. Our other covered topics include:
  - * b-hadron production fractions,
  - * lifetimes and mixing parameters of b hadrons,
  - * decays of b-hadrons into open or hidden charm hadrons, and into charmless final states,
  - * charm decays,
  - * tau lepton properties.
- The full and updated report will be available soon.

Acknowledgements

Markus Prim thanks the Argelander Program, the University of Bonn and the BMBF for their support.

Bundesministerium für Bildung und Forschung

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