# Flavor Physics

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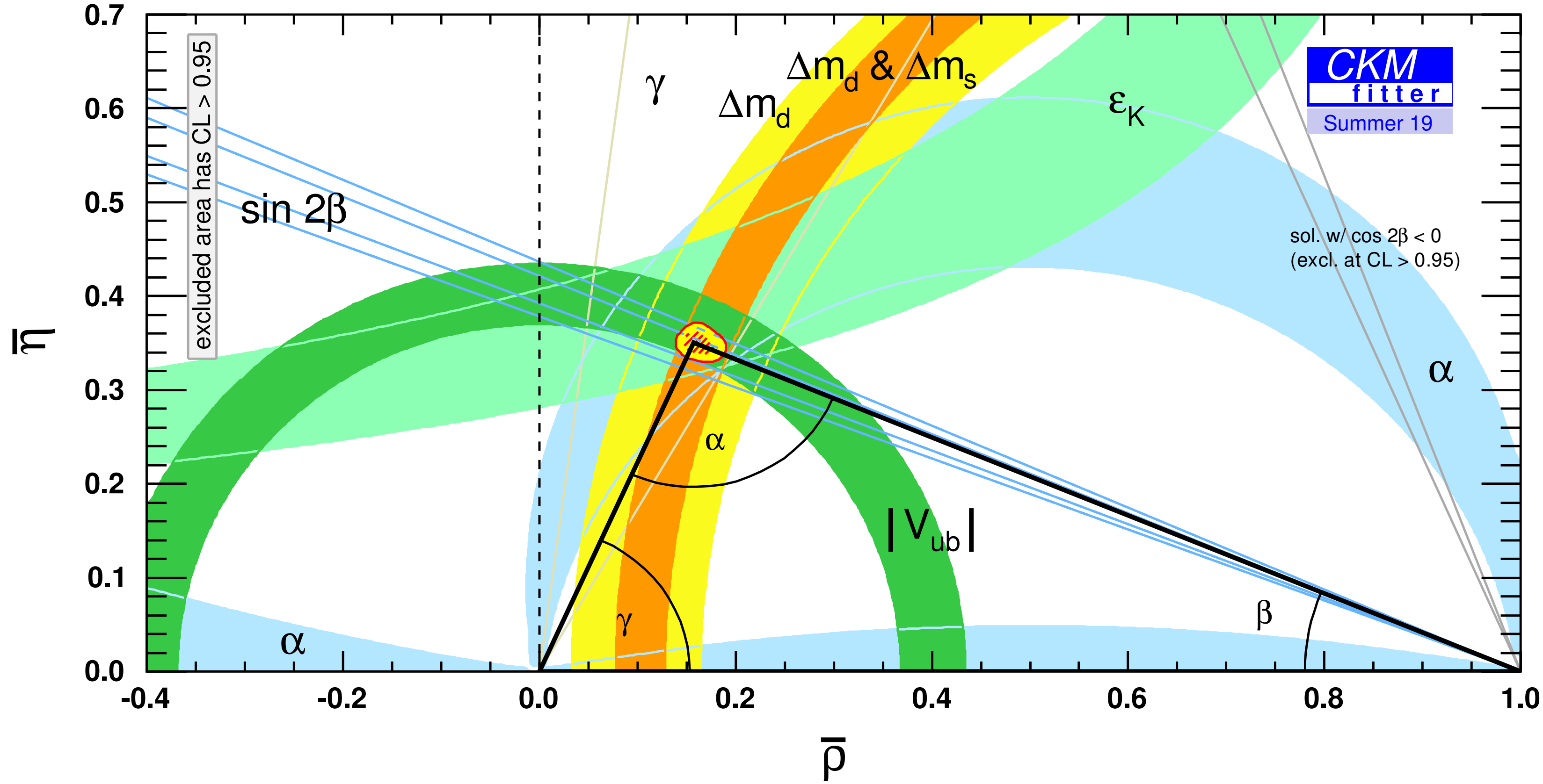
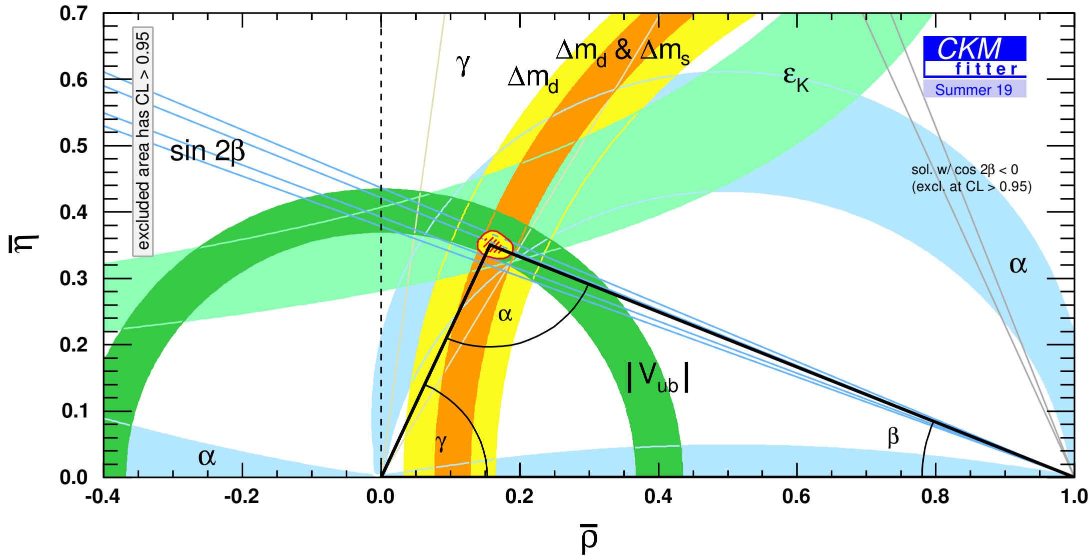
# Status of flavor physics



# The goals of flavor physics (1)

Finding hints for BSM physics




# The goals of flavor physics (2)

The weak/strong interplay

- Traditional: Overcome QCD to probe the weak interaction
  - Eliminate or calculate QCD parameters
- New: Use the weak interaction to probe QCD
  - Measure QCD parameters

# $B$ physics

# $B$ Physics

- $B$ physics is not a teenager anymore
- What next?
  - Anomalies
  - The future is bright: more data with clean modes
  - Theory developments are keep coming

# Higher order SU(3) sum rules

- Use the approximate symmetries of QCD
  - Isospin: $u - d$
  - SU(3): $u - d - s$
  - U-spin: $d - s$
- Isospin is very useful as the breaking is of $O(1\%)$
- SU(3), or just U-spin, is useful but it comes with large breaking of $O(20\%)$
- We can use SU(3) to
  - Estimate isospin breaking effects
  - Get rough predictions
  - Get precise predictions when we used relations that hold to higher order in SU(3) breaking

# All order U-spin sum rules

M. Gavrilova, YG, S. Schacht, in preparation

- We show how to get U-spin sum rules in any system without the need to decompose the amplitudes
- The system is mapped into a multi-dimensional geometrical lattice
- Sum rules that are valid to order $b$ correspond to $b$ dimensional subspaces
  - point: leading order
  - line: first order
  - plane: second order
- It is not clear, however, how useful it is in practice

# Charm physics

# The birth of charm CPV

Born in 2019, Charm CPV is a two years old baby

What is next for charm CPV?

- We can learn about QCD from charm
- We have SU(3)-based rough SM predictions to test

Kagan, Silvestrini, arXiv:2001.07207

YG et al. in preparation

# The small parameters for charm

We can estimate all the parameters in charm in terms of the following small parameters

- Non-unitarity of the $2 \times 2$ CKM: $\varepsilon_{\rm NU} \sim 10^{-3}$
- SU(3) breaking: $\varepsilon_{\rm SU(3)} \sim 0.2$
- The Wolfenstein parameter of the CKM: $\lambda \sim 0.2$
- For example [$x \sim \Delta m$, $y \sim \Delta\Gamma$]
  - Theory: $x_{\rm th} \sim y_{\rm th} \sim \lambda^2 \varepsilon^2_{\rm SU(3)} \sim 0.2\%$
  - Experiment: $x_{\rm ex} \sim y_{\rm ex} \sim 0.5\%$

# There is a pattern

$$a_f \equiv \frac{\Gamma(D \to f) - \Gamma(\overline{D} \to \overline{f})}{\Gamma(D \to f) + \Gamma(\overline{D} \to \overline{f})} \approx a_f^d + a^m + a_f^i$$

1. $a_f^d$. For SCS

$$a_f^d \sim \varepsilon_{\rm NU} \times O(1)_f \sim 10^{-3}$$

2. $a^m$. Universal

$$a^m \sim y \frac{\varepsilon_{\rm NU}}{\varepsilon_{\rm SU(3)}} \sim \varepsilon_{\rm NU} \times \varepsilon_{\rm SU(3)} \sim 10^{-4}$$

3. $a_f^i$. Approximate universality

$$a_f^i \sim x \frac{\varepsilon_{\rm NU}}{\varepsilon_{\rm SU(3)}} \times \left[1 + O(\varepsilon_{\rm SU(3)})_f\right] \sim 10^{-4} \pm 10^{-5}$$

# Kaon physics

# Kaon Physics

- Kaon CPV was “born” in 1964
- Mature, but clearly not retired yet
- NA62 and KOTO look for the clean $K \to \pi\nu\bar{\nu}$ modes
- What about $K \to \mu\mu$?

# $K \to \mu\mu$

- Rare FCNC decay
- It was very important in developing the SM: the GIM mechanism
- The $K_L$ rate was measured, while LHCb is looking for the $K_S$ rate

$$\mathcal{B}(K_L \to \mu\mu) \approx 7 \times 10^{-9} \qquad \mathcal{B}(K_S \to \mu\mu) \sim 5 \times 10^{-12}$$

- Can we get a clean theoretical information from it?

# $K \to \mu\mu$

G. D'Ambrosio, T. Kitahara, 1707.06999

A. Dery, M. Ghosh, YG, S. Schacht, 2104.06427

Can we get a clean theoretical information from it?

**Yes**

- By exploiting the interference term we can get a clean information regarding CPV
- We can measure $\mathcal{I}m(V_{td}V_{ts}^*)$, which is the same parameter that we can get from $K_L \to \pi\nu\bar{\nu}$
- Theoretical uncertainties below $1\%$

# Conclusion

# What next for flavor?