# CPV in $B$

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# The CPV family

- Kaon CPV was "born" in 1964
  - Mature, but clearly not retired yet

- $B$ CPV was "born" in 2000
  - Not a teenager anymore
  - Ready for prime time

- Charm CPV was "born" in 2019
  - Still a baby. So much to explore

# The future of $B$ CPV

What next?

- We should have much more data on all types of $b$ hadrons
- Can we find clever ideas to improve on theory clean modes, like $B \to DK$?
- Can theory do better in places like $B \to \psi K_S$, $B \to \pi\pi$?
- How can we utilize baryons?
- Can we use "triple products"?
- Can we use $SU(3)$ to get precise results?

# Questions for theory

# $B \to DK$ to get $\gamma$

- Theory champion: The most precise theoretically
- With more data, we expect about $1\%$ error on $\gamma$ around 2030
- Can we find smarter ways to do even better?
  - Maybe better binning as we get more charm data?
  - Can "no binning" methods do better than smart binning?

# $B \to \psi K_S$

- The penguin uncertainty is at a few permil level

$$b \to c\bar{c}s \propto V_{cb} \qquad b \to sg \to sc\bar{c} \propto V_{ts}$$

  - $B \to K\pi$ indicates that penguins are $O(20\%)$
  - The phase is $Im(V_{ts}/V_{cb}) \sim O(\lambda^2) \sim 5\%$
  - So the effect is naively of order $1\%$.
- Experimental errors are reaching that level
- Can we do better?
- Not easy to estimate these hadronic parameters
  - Use SU(3) and $B \to \psi\pi$ (0809.0842)
  - Penguin OPE (1503.00859)
  - Can we do better? Can we use also $B \to \phi K_S$?

# $B \to \pi\pi$ and friends

- Experiments are at the level of theory uncertainties of order few percents from isospin breaking
- Can we do better?
- Estimate the breaking correction and the reminding uncertainties are at the $1\%$ level (hep-ph/0502139; 1705.02981)
- In $B \to 3\pi$ or $B \to 4\pi$ we have observables that are second order in isospin breaking

# Baryons

- What can we learn from $B$ decays into baryons?
- What extra information can we get from $\Lambda_b$ decays?
- Naively, it is just more statistics, but there is the spin information
- Polarized $\Lambda_b \to \Lambda \ell^+ \ell^-$ (hep-ph/0202103) and $\Lambda_b \to \Lambda \gamma$ (hep-ph/0702191)
- I do not recall anything where the spin is used to study CPV. Do I miss anything? Can it be used?

# "triple products"

- Most CPV observables we talk about are "rate asymmetries" that require a weak and a strong phase
- We can get CPV without a strong phase from a triple product of three independent vectors

$$\vec{p}_1 \cdot (\vec{p}_2 \times \vec{p}_3)$$

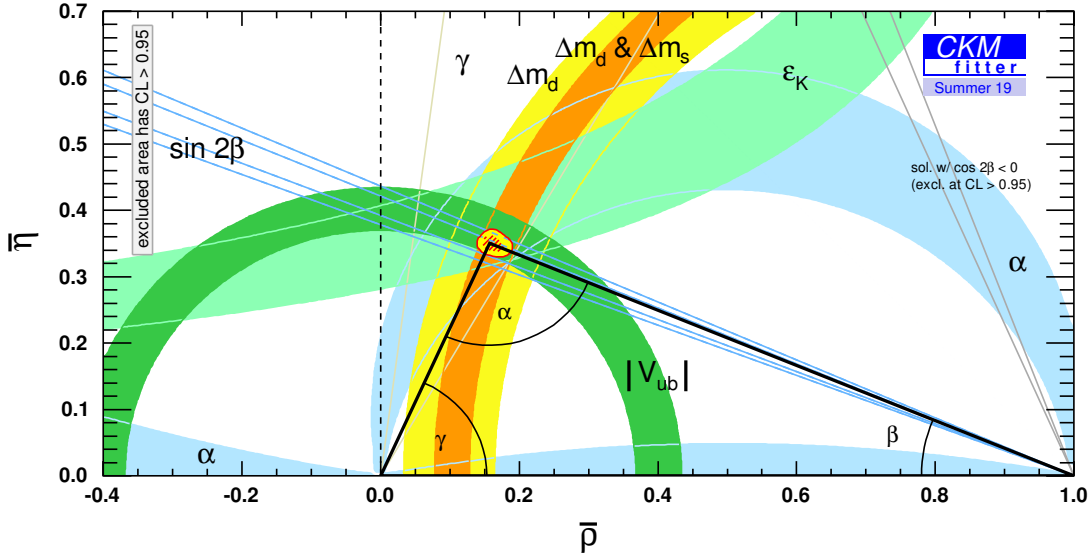
- We can probe it with "up-down" asymmetry
- There are many more observables (1508.03054)
- How can we use them to probe the SM?

# Higher order SU(3)

- Isospin is very useful as the breaking is of $O(1\%)$
- SU(3) or just U-spin are cool but with large breaking $O(20\%)$
- We can use it to
  - Estimate corrections, like isospin corrections
  - We can use it alone if we can get observables that are higher order in the breaking
  - We have some ideas on how to do it, need more work

# Conclusion

# 2020 to 2030


CKM fitter
Summer 19
excluded area has CL > 0.95
sin 2β
γ
Δm_d
Δm_d & Δm_s
ε_K
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
α
|V_ub|
β
ρ̄
η̄