Status of flavor physics

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Flavor visits the Dr.

Dr: How are you?

Flavor: Overall good, but I have some issues

Dr: Yes, I heard about them, they are all over the internet

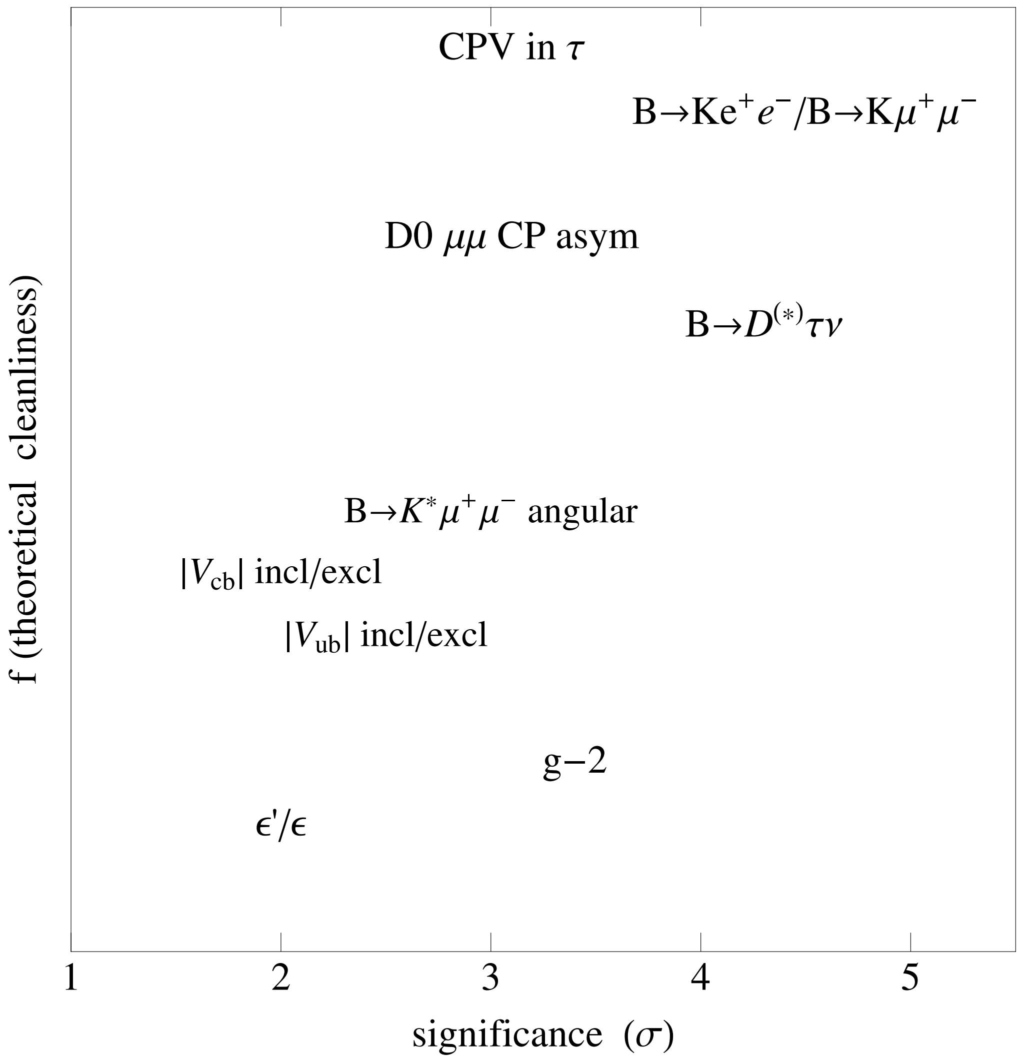
Flavor: What do you think we can do?

Dr: More lab tests

We have hints for BSM, but we need to wait for more data

Are we seeing the tail?

The Zoltan plot



Is one (or more) of them real?

I will talk on four of them (See also M. Blanke, 1708.06326)

- $R(D^{(*)})\,:\; b \to c\tau\nu$
- $R(K^{(*)})$ and $P_5'\,:\; b \to s\ell^+\ell^-$ spectrum and angular
- CPV in $\tau \to K_S\pi\nu$

For each, we will ask

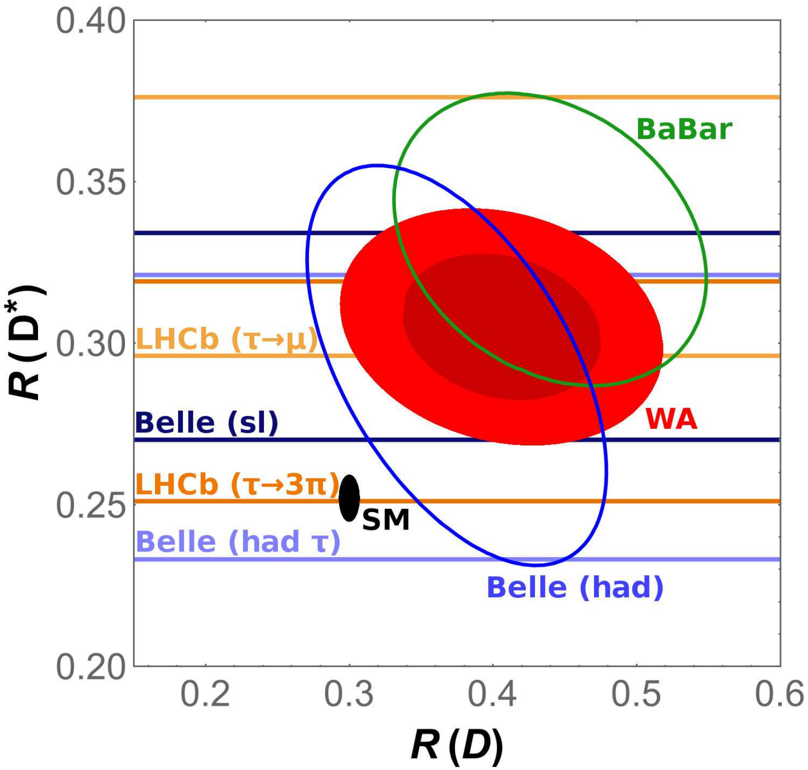
- Can it be a miscalculation of the SM prediction?
- Can it be due to NP?
- Can it be a statistical fluctuation and/or an unknown systematic effect?

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

$R(D^{(*)})$: The data

$$R(D) \equiv \frac{\Gamma(B \to D\tau\nu)}{\Gamma(B \to D\ell\nu)} \qquad R(D^*) \equiv \frac{\Gamma(B \to D^*\tau\nu)}{\Gamma(B \to D^*\ell\nu)}$$

M. Jung



- $\ell = e, \mu$
- $R \neq 1$ due to PS
- Babar, Belle, LHCb
- B^0, $\bar{B}^0$, B^+, B^-
- $\sim 4\sigma$ from the SM
- Also $\Gamma(B_c \to J/\psi\tau\nu)$

$R(D)$: what can we say?

$$R(D) \equiv \frac{\Gamma(B \to D\tau\nu)}{\Gamma(B \to D\ell\nu)} \qquad R(D^*) \equiv \frac{\Gamma(B \to D^*\tau\nu)}{\Gamma(B \to D^*\ell\nu)}$$

- Data $\sim 4\sigma$ away from the SM
- The predictions are very clean because a lot is canceled in the ratios
  - It is just the mass of the lepton that is different
  - From factors at somewhat different kinematics
  - The effect of one form factor scales like the lepton mass

Can it be the SM?

- A tree level decay in the SM
- The SM rate is off by about 30%
- The effect of the “heavy” form factor is known up to

$$\frac{m_\tau \Lambda_{\rm QCD}}{m_B^2} \sim 3\%$$

- More can be found in Bernlochner, Ligeti, Papucci, Robinson, 1703.05330

It is hard to think that the effect is purely due to unknown SM effects

What kind of NP is it?

- Without interference, we need 50% effect in the amplitude
- With interference, it can be 15%
- Must be tree level
  - A charged Higgs
  - A W'
  - A scalar or vector leptoquark
- There are tensions in each of these models
- None of these models are “nice” (whatever nice means)
- There is a model building challenge that has not been met yet

How to check for NP?

Some ideas of other observables

- Measure the inclusive $b \to c\tau\nu$ and $\Lambda_b \to \Lambda_c\tau\nu$ as they probe a aifferent combination of operators
- Depend on the oprator, the NP can change the spectrum
- Because the ν is a doublet, we must also have a $b\bar{b}\tau^+\tau^-$ or $c\bar{c}\tau^+\tau^-$ operator
  - $\tau\tau$ production at high energy
  - Υ and ψ leptonic decay
- Can lead to CP violation in $B \to D^{**}\tau\nu$ decays

$R(D)$ Bottom line

My best guess

- The SM predictions are robust at the 5% level.
  - Cannot explain the effect
- NP models are not “nice”
  - Just does not feel right
- The experiments did a very good job
  - Hard to see an unknown systematics

Bottom line: I have no idea. We need more checks

R_K and friends

$b \to s\ell^+\ell^-$

Mainly LHCb

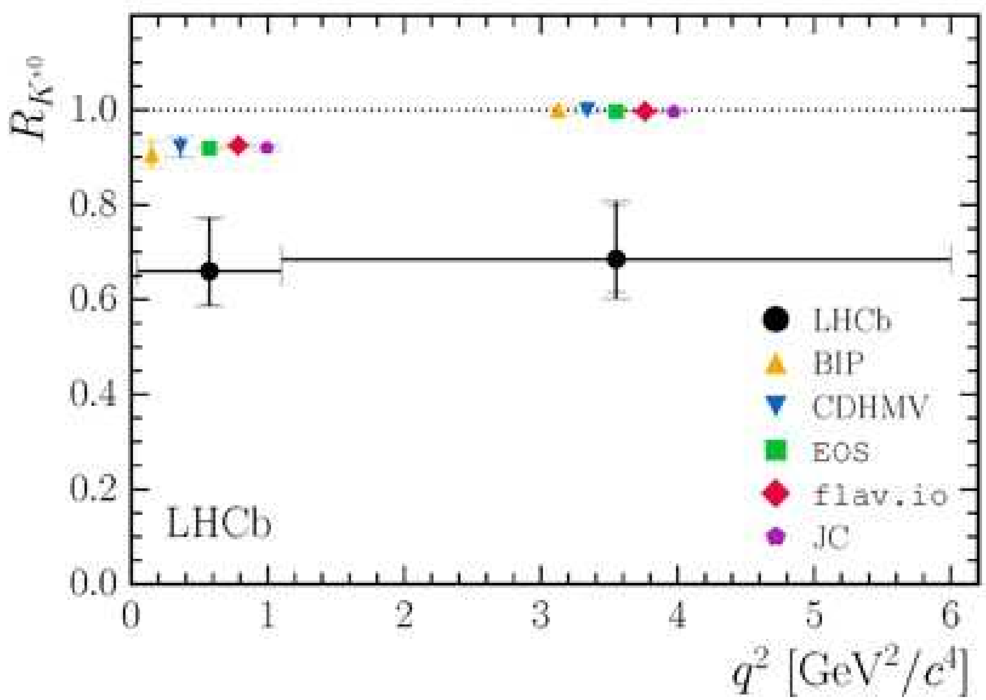
- Angular distribution in $B \to K^*\mu^+\mu^-$
  - with $K^* \to K\pi$ it is a four body decay
- The ratio

$$R(K^*)[q^2] \equiv \frac{\Gamma(B \to K^*\mu^+\mu^-)}{\Gamma(B \to K^*e^+e^-)}$$

- The ratio

$$R(K)[q^2] \equiv \frac{\Gamma(B \to K\mu^+\mu^-)}{\Gamma(B \to Ke^+e^-)}$$

$b \to s\ell^+\ell^-$: Data



- 2 bins in $R(K^*)$ with $\sim 2.5\,\sigma$
- 1 in $R(K)$ with $\sim 2.5\,\sigma$
- Angular distibution with $\sim 3.7\,\sigma$

Can it be SM?

- The μ/e spectrum:
  - A very large effect at small q^2
  - For large q^2, radiative corrections are at the 1% level
- For the angular distribution: “charming penguins”?
  - Some people say it is possible, some not

Yet, when you put it all together it clearly cannot be due to miscalculations in the SM

Q: Can it be NP?

A: Yes, but none of the models is “nice”

“A model building challenge that has not been met yet”

$R(K)$ Bottom line

My best guess

- The SM predictions are robust at the 1% level for the LFV, much less for the angular distribution
  - The SM cannot explain all the effect
- NP models are not “nice”
  - Just does not feel right
- The experimental situation got a lot of attention.
  - Unlikely an experimental issue

Bottom line: Again, we need more tests

CPV in τ

BaBar CPV in $\tau \to K_S \pi \nu$

$$A \equiv \frac{\Gamma(\tau^+ \to K_S \pi^+ \bar{\nu}) - \Gamma(\tau^- \to K_S \pi^- \nu)}{\Gamma(\tau^+ \to K_S \pi^+ \bar{\nu}) + \Gamma(\tau^- \to K_S \pi^- \nu)}$$

- In the SM we expect CPV of order ϵ_K
- No theoretical uncertainty! The theoretical error is from the experimental measurement of ϵ_K
- BaBar in 2011 found a 3 sigma effect

$$A_{\rm exp} = -0.36 \pm 0.23 \pm 0.11$$
$$A_{\rm the} = +0.36 \pm 0.01$$

Can it be SM?

$$A_{\text{exp}} = -0.36 \pm 0.23 \pm 0.11$$
$$A_{\text{the}} = +0.36 \pm 0.01$$

- How can we explain it?
- Could it be an odd number of sign mistakes?

The SM prediction is very solid

Can it be NP?

How many papers have been written about it?

zero

- It cannot be due to NP
- It cannot be a wrong SM calculation
- It is a statistical and/or a systematic effect

Conclusions

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I hope it is the tail, but I am skeptical