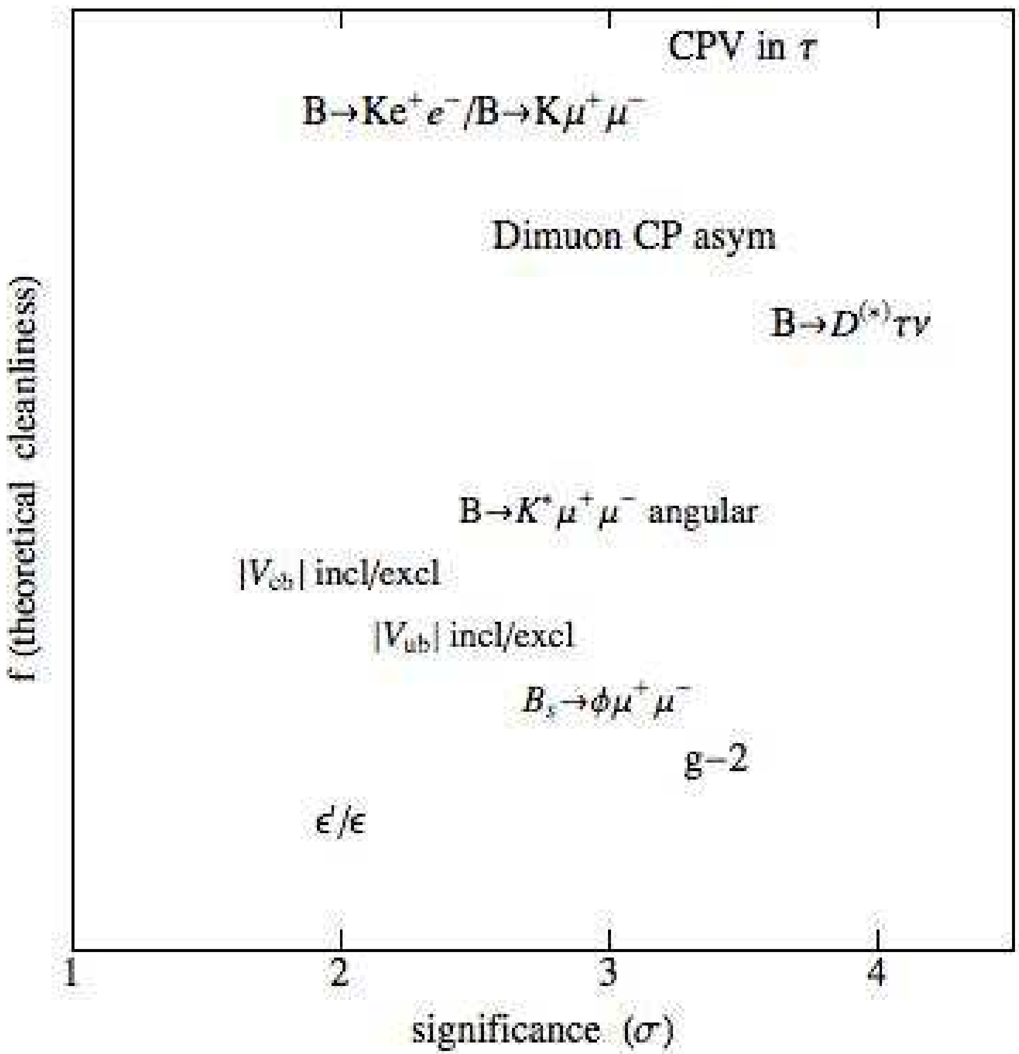
Flavor physics

Yuval Grossman

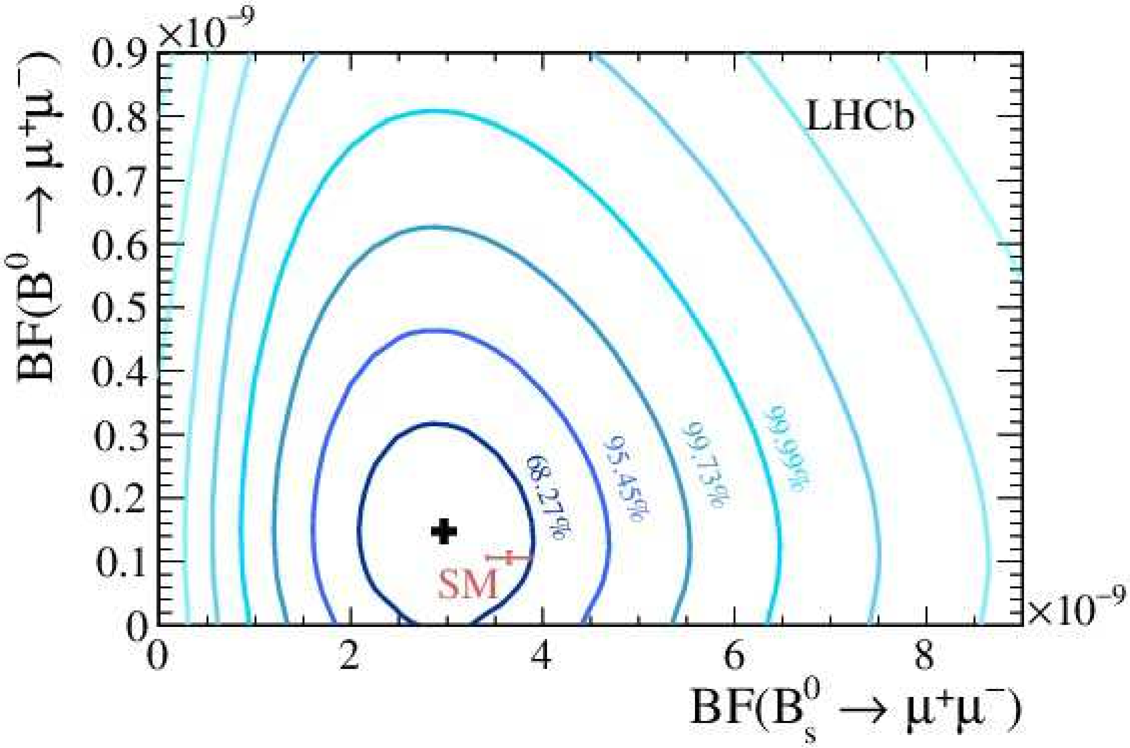
Cornell

Where is the tail?

The Zoltan plot



New this winter



- It was a hint for NP a while ago
- From a model building point of view, not much has changed. ϵ_K is still the king

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

- 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 found a 2.8 sigma effect

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

- How can we explain it?
  - Could it be an odd numbers of sign mistakes?
  - Can it be BSM?

The near future

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New experiments and more data

- Soon: Belle2, NA62 ($K^+ \to \pi^+ \nu\bar{\nu}$)
- We expect more data. In about 10 years

$$\frac{\text{Belle II}}{\text{Belle}} \sim \frac{\text{LHCb total}}{\text{LHCb now}} \sim 100$$

- As theorists, what do we need to do in order to get ready for the data

The problem is QCD

How to overcome QCD?

- Calculate it! Aka lattice QCD
- Measure it! In some cases we can have more measurements than parameters
- Use approximate symmetries. These symmetries help us reduce the number of parameters to reach

$$\#(measurements) > \#(parameters)$$

  - Isospin with $\delta \sim 1\%$
  - SU(3) with $\delta \sim 20\%$

Beyond leading order

- SU(3) was not used for precision measurements, but only for order of magnitude estimates
- Isospin was used in many cases. In ten years we anticipate isospin breaking effects to become the dominant uncertainty
- Can we incorporate high order effects?
  - We can use models to calculate the corrections
  - Can we do it in a model independent way?

Flavor sum rules

What is a sum rule?

For example

$$A(B^0 \to \pi^+\pi^-) + \sqrt{2}A(B^0 \to \pi^0\pi^0) = \sqrt{2}A(B^+ \to \pi^+\pi^0)$$

- There are also sum rules for CP asymmetries and for rates
- What assumptions are used in order to obtain a sum rule?

The assumptions of sum rules

Some amplitudes vanish

- Isospin and physical amplitudes: a basis rotation
- H can be decomposed into Isospin representations
- We get a sum rule because H is not generic
- Back to $B \to \pi\pi$
  - 3 physical decays: $A_{00},\ A_{+-},\ A_{+0}$
  - 3 isospin amplitudes

$$\langle 0|1/2|1/2\rangle \quad \langle 2|3/2|1/2\rangle \quad \langle 2|5/2|1/2\rangle$$

  - To leading order, $b \to qqq \Rightarrow I(H) \leq 3/2$
  - Thus $\langle 2|5/2|1/2\rangle = 0$ and we get a sum rule

Higher order

We have a systematic expansion

- Two sources: quark masses and QED. Both $\propto (u\bar{u} - \bar{d}d)$ and give a triplet breaking
- The breaking spurion is a triplet M
- Then $M \times H = 5/2$ is possible and $\langle 2|5/2|1/2\rangle \neq 0$
- Thus to leading order in Isospin breaking there is no sum rule

B to n pions

- There are $n + 1$ $B \to \pi\pi\pi...$ decay modes
- The highest H has $3/2$
- Thus we need $n - 1$ insertions of M to get it
- In principle (!) we can get a sum rule that holds to a very high order
- It is not clear yet how we can use it in order to get a better determination of CKM parameters

Conclusions

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- The tail problem, to me, is a severe one
- Not much new in terms of bounds on weak scale physics
- We need to get ready for the next round of experiments, and there are some ideas in that direction