New era in flavor physics

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Outline

- Introduction and bottom line
- The NP flavor problem
- Specific clean modes
- Conclusions

Introduction and bottom line

The three parts

You should know

- Where are you coming from
- Where are you going to
- Who you should report to

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The third item is easy... Lets talk about the first two

Where are we coming from

- The SM is doing very well: both the gauge sector and the flavor sector
- There are many reasons to think there is NP at the TeV
- It is hard to understand why we do not see any indications of this NP
  - The little hierarchy problem
  - The NP flavor problem

Where are we going to

- Find the NP
  - Directly at the LHC
  - Indirectly at LHC-b, super-B factories, ...
- Try to look for evidences for NP in all possible ways
- Once we found the NP we need to understand it
- Two complementary ways: Direct probe (LHC) and indirect probe (flavor)
- Practically impossible to understand the NP only with the LHC

The bottom line

There is no absolute “target” of how far we like to go. The real goal is

$$\sigma_{\rm exp} \ll \sigma_{\rm the}$$

The new physics flavor problem

The SM is not perfect...

- We know the SM does not describe gravity
- At what scale it breaks down?

We parametrize a scale as the denominator of an effective higher dimension operator. The weak scale is roughly

$$\mathcal{L}_{\rm eff} = \frac{\mu\, e \nu \bar{\nu}}{\Lambda_W^2} \Rightarrow \Lambda_W \sim 100 \text{ GeV}$$

- The effective scale is roughly the masses of some heavy fields times unknown couplings
- Flavor bounds give $\Lambda \lesssim 10^4 \text{ TeV}$

Flavor and the hierarchy problem

There is tension:

- The hierarchy problem $\Rightarrow$ $\Lambda \sim 1$ TeV
- Flavor bounds $\Rightarrow$ $\Lambda > 10^4$ TeV

Any TeV scale NP has to deal with the flavor bounds

$$\Downarrow$$

Such NP cannot have a generic flavor structure

Flavor is mainly an input to model building, not an output

The new physics flavor problem

The SM flavor puzzle: why the masses and mixing angles exhibit hierarchy. This is not what we refer to here

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The NP flavor problem (know also as the SUSY flavor problem or the RS flavor problem)

- How come the new TeV scale physics has no effect on flavor observables?

Dealing with flavor

Any viable NP model has to deal with this tension. Thus, the NP at the TeV must not be generic

- At what level we expect to see deviations from the SM predictions?
- There is no simple answer. Naively, we should have seen it already
- One class of models can accommodate “large” flavor violations. That is, as large as current bounds
- The other is Minimal Flavor Violation (MFV): The NP at the TeV has minimal impact on flavor
- Roughly, even in MFV we expect $O(1\%)$ effects. Clearly the exact numbers and modes are important

The goal of flavor physics

Flavor physics must look for problems with the SM in order to see the nature of the NP

- “past”: Confirmation that the SM explain flavor physics at leading order
- “future”: Looking for small deviations from SM predictions. As a rough guideline aiming at the 1% level
- The main issue is theoretical uncertainties, that is, QCD. The name of the game is to try to overcome QCD and get to the fundamental physics

The SM flavor sector

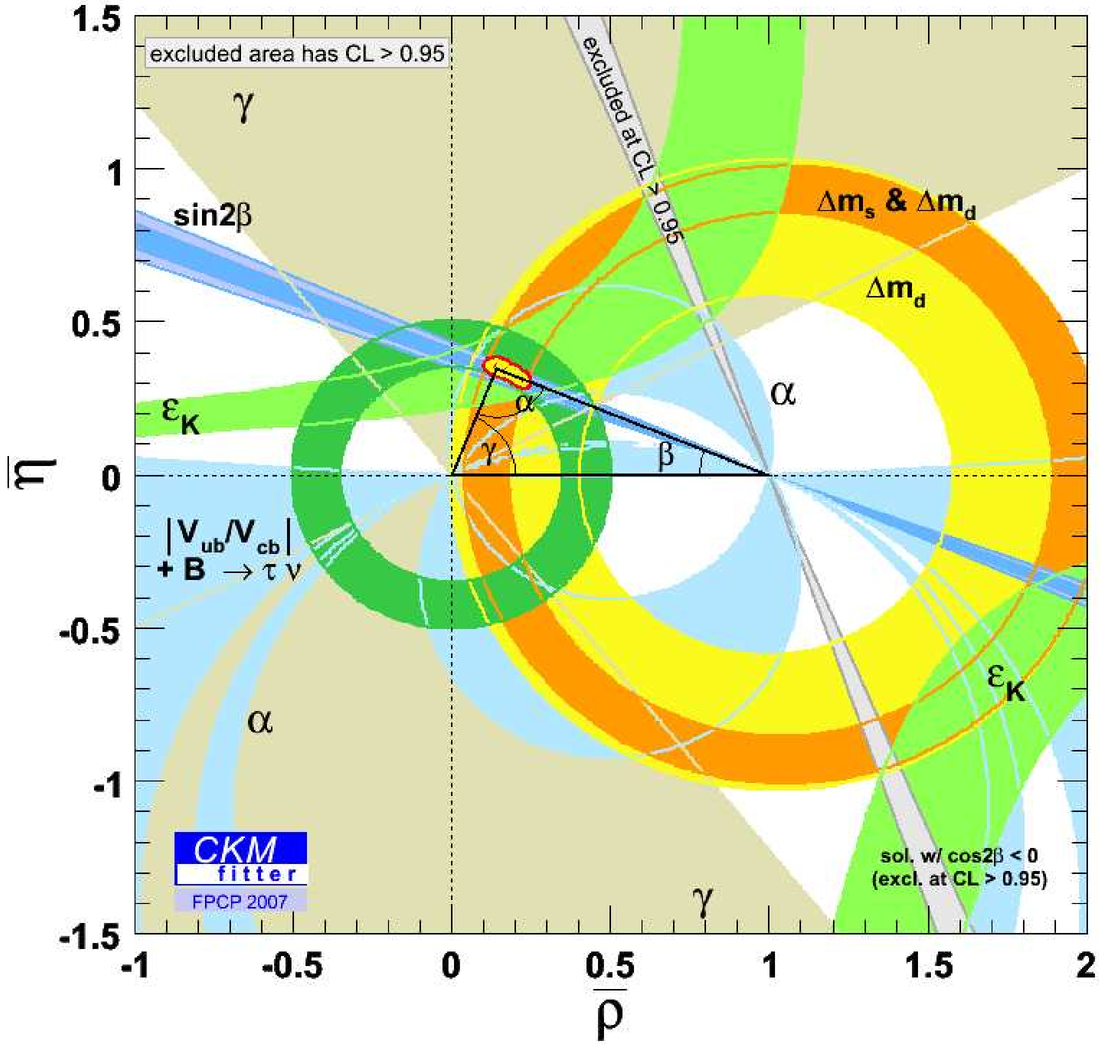
At present there are no significant deviations from the SM predictions in the flavor sector

There are some hints

- Global fit
- $a_{\rm CP}(B \to \psi K_S)$ vs $a_{\rm CP}(B \to \phi K_S)$
- $B \to K\pi$

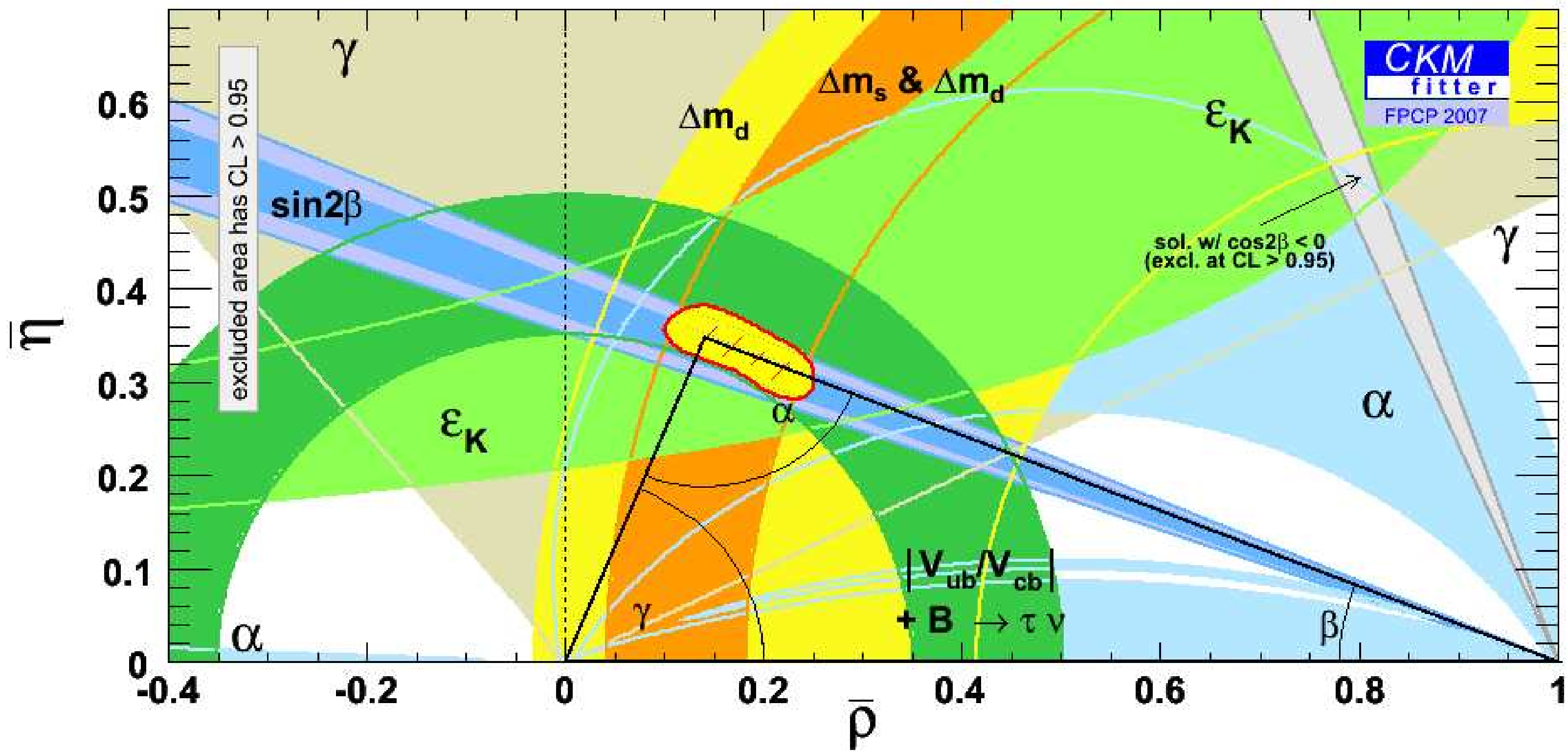
It is puzzling why it is so good

Global fit



excluded area has CL > 0.95
excluded at CL > 0.95
γ
sin2β
Δm_s & Δm_d
Δm_d
α
ε_K
β
$|V_{ub}/V_{cb}|$
+ B → τ ν
sol. w/ cos2β < 0
(excl. at CL > 0.95)
CKM fitter
FPCP 2007
$\bar{\eta}$
$\bar{\rho}$

Global fit (zoom in)



- Very impressive agreement
- or really puzzling?

Where should we look?

Where should we look?

- Many modes: one mode is not enough
- Modes with very small theoretical uncertainties
- Measurements that can be done in low energy machines like a super-B factory, LHC-b, Kaon, ...

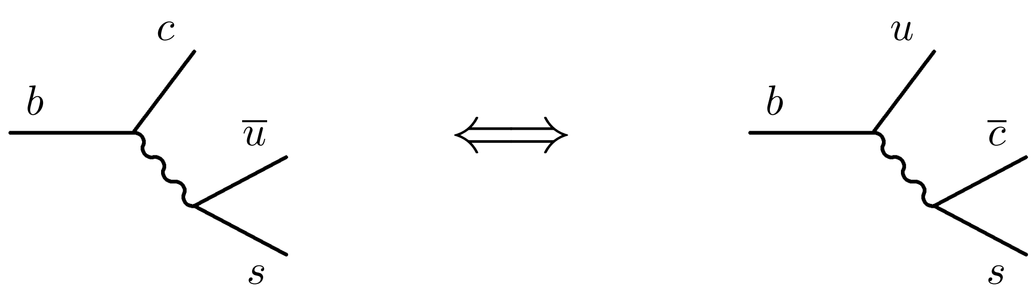
There are many interesting and accessible modes

My list (please add your mode now)

- Almost done
  - $B \to \psi K_S$
  - $b \to s\gamma$
  - V_{cb}
- To the future
  - $B \to DK$
  - CP asymmetries in penguin modes
  - $B \to K\pi$
  - CP asymmetries in D mixing and decay
  - CP asymmetries in B_s decays
  - $K \to \pi\nu\bar{\nu}$

γ with $B \to DK$

Use interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$



Interference between

$$B^+ \to DK^+ \quad \text{follows by} \quad D \to f$$
$$B^+ \to \overline{D}K^+ \quad \text{follows by} \quad \overline{D} \to f$$

f can be any common final state to D and $\overline{D}$

$B \to DK$

By far the best mode in terms of theoretical error

- No error at leading order in the weak interaction

$$\frac{\Delta\gamma}{\gamma} \lesssim 10^{-4}$$

- All hadronic parameters can be measured
- The D is a long lived intermediate particle. Thus we have more modes than parameters

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Need statistics

- "Easy" at super-B (?)
- What about LHC-b?

CP asymmetries in $b \to s\bar{s}s$ modes

- Time dependent CP asymmetries measure the phase between the mixing and twice the decay amplitudes
- In the SM
  - $\arg(A_{mix}) = 2\beta$
  - $\arg(A_{b\to c\bar{c}s}) = 0$ (Tree)
  - $\arg(A_{b\to s\bar{s}s}) = 0$ (Penguin)
- To first approximation the SM predicts

$$a_{\rm CP}(B \to \psi K_S) = a_{\rm CP}(B \to \phi K_S) = \sin 2\beta$$

- The theoretical uncertainties are small. The question is how small. Can we go down to $\sigma_{\rm exp} \sim 2\%$?

$b \to s\bar{s}s$ theory

Using related CP conserving data there are two ways to go

- Using SU(3): limited, too conservative. Can go down to few $\%$ in few simple modes, like $K\pi$
- Calculate: also hard. Despite the progress, we cannot trust fully hadronic calculations to the few present level

At present we are not at the 2% level yet. I am optimisitc that in few years we can go there

$B \to K\pi$

Consider the four decays

$$
\begin{array}{lll}
B^+ \to K^0\pi^+ & b \to d\bar{d}s & \\
B^+ \to K^+\pi^0 & b \to d\bar{d}s \quad \text{or} \quad b \to u\bar{u}s & \\
B^0 \to K^+\pi^- & b \to u\bar{u}s & \\
B^0 \to K^0\pi^0 & b \to d\bar{d}s \quad \text{or} \quad b \to u\bar{u}s &
\end{array}
$$

- There are many SM relations between the rates and CP asymmetries of these modes
- To first approximation, all the rates are equal since the penguin diagram dominate
- This predicting power is there since we use isospin

The $B \to K\pi$ theory error

How far can we go? Naively, until we cannot trust isospin

- Naively isospin breaking is of order few $\times 10^{-2}$
- This is roughly at the level of the subleading T and P_{EW} amplitudes
- In some cases we can find “smart” relations where isospin breaking is only second order. This is the case for the Lipkin sum rule

We can hope to control theoretical uncertainties at the level of future experimental errors

A detour, before charm physics

How should we call it?

- A super-B factory
- A super-flavor factory

A detour, before charm physics

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- I think a super-flavor is better
- Zoltan Ligeti and Mark Wise disagree. They say this is not correct English. What about Japanese?

D mixing and decay

- Many observables are very hard to predict. Very large theoretical uncertainties
- For example x and y can be calculated, at best, to a factor of ten
- Yet, there are very clean observables, those that are CP violating
- The reason is that the D system is almost purely two generation, so it is CP conserving in the SM
- Very nice in term of flavor physics. Probe other aspect of it
- There are flavor models that "put" all the flavor structure in the up sector

B_s decays

- Similar to the B and D case, many CP asymmetries can be predicted to high accuracy
- Again, complementary to B data

$K \to \pi\nu\bar{\nu}$

- By now it is known that this decay is very clean
- The reason is that we can use isospin and perturbation theory
- Eventually we hit theoretical error due to higher order effects and isospin breaking
- Experimentally it is very hard to get to that limit
- Measuring these decays at the 1% level will be a great complmentary way to probe flavor

Final remarks and Conclusion

What next for flavor physics?

- We do not know what is the NP
- So far, it hides very well
- Even after we find it, it will be impossible to understand it without low energy data
- We need to push in all directions