FPCP2013: Theory Summary

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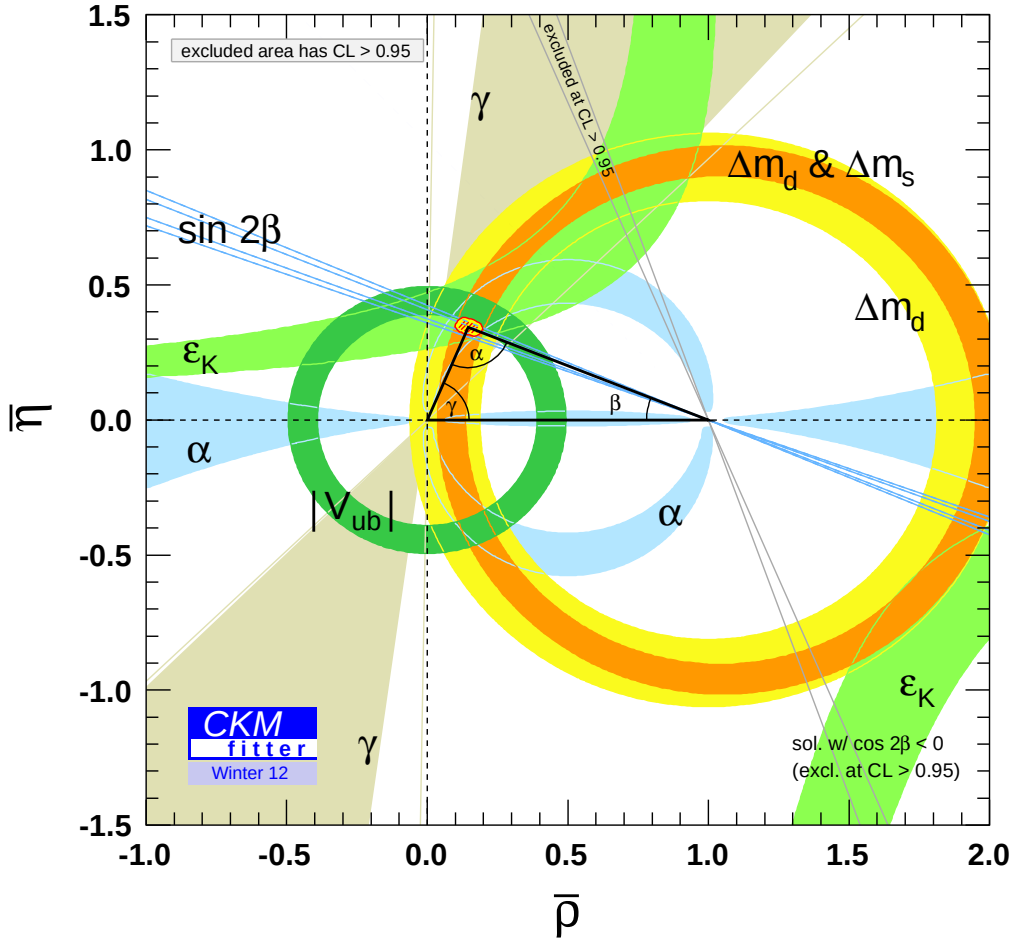
A plot


excluded area has CL > 0.95
excluded at CL > 0.95
γ
Δm_d & Δm_s
sin 2β
Δm_d
ε_K
α
β
γ
|V_ub|
α
ε_K
CKM fitter
Winter 12
γ
sol. w/ cos 2β < 0
(excl. at CL > 0.95)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
η̄
ρ̄

Summary

The SM works

Summary

The SM works too good

Status of the SM

Recent triumphs and issues

- Triumphs
  - CPV in $B_s \to K\pi$
  - CPV in charm
  - Λ_b lifetime
- Unsolved issues
  - CPV in $B \to K\pi$
  - $B \to D^{(*)}\tau\nu$
  - CPV in $\tau \to K_S\pi\nu$
  - Semileptonic CP asymmetry
  - Top FB asymmetry
  - $g-2$

Beyond the SM

Why do we think there is NP?

Two types of reasons: data and beauty

- Data
  - Dark matter
  - Baryogenesis
  - Inflation, dark energy
  - Neutrino masses (?)
- Beauty
  - Cosmological constant
  - Hierarchy problem
  - Flavor hierarchy problem
  - The strong CP problem
  - All the hints for a GUT

History of physics

Both types of problems led to new discoveries

- Data
  - Black body radiation
  - Constant of speed of light
  - Discovery of the top
- Beauty
  - The periodic table was a hint
  - Charm was predicted based on beauty
  - ...
- At times things are mixed: Relativity was discovered based on beauty and it helped to solve data problems

How to look for NP?

- There are two ways to find NP
  - Find new states (direct)
  - Find virtual effects of new states (virtual)
- Direct give more information, but limited in reach
- Virtual give more reach, but may not be unique
  - EWP: 10^4 GeV
  - Flavor: 10^8 GeV
  - Neutrinos: 10^{15} GeV
  - Proton decay: 10^{16} GeV
  - CPT and Lorentz violation $> M_{Pl}$

Why flavor

Why flavor?

Flavor is interesting

- Fermion masses are (mainly) small and hierarchical
- FCNCs are very small
- The charged current is universal
- Quark mixing angles are small and hierarchical
- The patterns of leptons and quark flavors are different

Flavor seems to have a lot to tell us

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

The SM flavor structure is special

- Universality of the charged current interaction
- FCNCs are highly suppressed

Any NP model must reproduce these successful SM features

The new physics flavor scale

- K, D and B physics:

$$\frac{s\bar{d}s\bar{d}}{\Lambda^2} \quad \Rightarrow \quad \Lambda \gtrsim 10^5 \text{ TeV}$$

- Charged leptons:

$$\frac{\mu\bar{e}f\bar{f}}{\Lambda^2} \quad \Rightarrow \quad \Lambda \gtrsim 10^3 \text{ TeV}$$

- There is no exact symmetry that can forbid such operators
- All other bounds on NP, like proton decay, maybe due to exact symmetry

Flavor and the hierarchy problem

There is tension:

- The hierarchy problem $\Rightarrow$ $\Lambda \sim 1$ TeV
- Flavor bounds $\Rightarrow$ $\Lambda > 10^5$ TeV

This tension is the NP flavor problem

Any TeV scale NP has to deal with the flavor bounds

$\Downarrow$

Such NP cannot have a generic flavor structure

Where is the tail?

Where is the tail (again)?

- Weak decay
- Atomic parity violation
- Cross section in $e^+e^- \to \mu^+\mu^-$ at low energy

I feel that the “tail problem” is the most severe one in HEP

The hierarchy problem

Closer look at the "beauty" problems

- Cosmological constant
- Hierarchy problem
- Flavor hierarchy problem
- The strong CP problem
- All hints for GUT

Q: Which one of these problems is more "pressing"?

Most common answer: the CC, because it involves a 10^{120} fine tuning and we have no theoretical idea

OJ Simpson and the hierarchy problem

What are the "promising" problems

- Problems are hints for something deeper
- All these hints give the same "probability" to find NP

$$1 - P \approx 1$$

- The hierarchy problem is different as the scale associated with it is the weak scale
- GUTs have a scale, but it cannot be probed directly
- The flavor problem does not have a scale

Bottom line: We think there is physics beyond the SM, but we do not (yet) know what it is

Why flavor (take 2)

Why flavor (take 2)

Our best way
to get a deeper
understanding
of Nature

Thank you!