CP3 Seminar : Spontaneous CP Violation

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Part 1

Spontaneous CP Violation

(SCPV) . . .

Spontaneous *CP* Violation

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- Why SCPV ?

  Because spontaneous breakings are more *natural* then explicit ones

Some Remarks

- Spontaneous breakings means VEV
- Only scalar fields may have VEV in order to preserve Lorentz invariance
- Only neutral fields may have VEV in order to preserve $U(1)_{em}$
- CP invariance implies real Yukawa coupling matrixes
- CP invariance implies real constants in the scalar potential

One Doublet ϕ (SM)

Impossible to have SCPV

The most general CP transformation is

$$(\mathcal{CP})\,\phi\,(\mathcal{CP})^{\dagger} = e^{i\vartheta}{\phi^{\dagger}}^{T}$$

with an arbitrary ϑ

If we choose $\vartheta = 0$, then the vacuum $\langle\phi\rangle = \binom{0}{v}$ is invaraint whatever the potential

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(non-trivial demonstrations)

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  if NFC is softly broken, we have SCPV but V_{CKM} is real

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Still some troubles in this way

Beyond SM : 1 doublet + 1 singlet (1)

- We add a non-Hermitian $SU(2) \otimes U(1)$-singlet scalar S to the SM
- It does not have any Yukawa interaction because all left-handed fields in the SM are in doublets $\Rightarrow$ no FCNYI

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The most general potential invariant under CP :

$$\begin{aligned} V =& \nu_1 \phi^\dagger \phi + l_1 \left(\phi^\dagger \phi\right)^2 + \nu_2 |S|^2 + l_2 |S|^4 + l_3 \left(\phi^\dagger \phi\right) |S|^2 \\ &+ \left[\nu_3 + l_4 |S|^2 + l_5 \left(\phi^\dagger \phi\right)\right] \left(S^2 + S^{\dagger^2}\right) + l_6 \left(S^4 + S^{\dagger^4}\right) \end{aligned}$$

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The VEVs are $\langle 0|\phi|0\rangle = \binom{0}{v}$ and $\langle 0|S|0\rangle = Ve^{i\alpha}$

If we assume

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BUT

As S does not have any gauge interaction, we can also choose

$$(\mathcal{CP})S(\mathcal{CP})^\dagger = S$$

Then, the vacuum is invariant under CP whatever the value of α

Beyond SM : 1 doublet + 1 singlet + 1 VLQ

The singlet has now interactions with the new isosinglet quark (N)

The Yukawa interaction, invariant under CP, is now

$$\mathcal{L}_Y = -\overline{Q}_L \Gamma \phi n_R - \overline{Q}_L \Delta \tilde{\phi} p_R - \mu \overline{N}_L N_R - \overline{N}_L \left(F S + F' S^\dagger \right) n_R + \text{H.c.}$$

with Γ, Δ, F and F' real

If we assume $(\mathcal{CP}) S (\mathcal{CP})^\dagger = S$ then $F' = F^*$

This won't be the case in general $\Rightarrow$ we are no longer allowed use this definition of CP

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Other interesting features :

- One can solve the strong CP problem
- Compatible with baryogenesis
- . . .