GDR Intensity Frontier - Arles

Nov 5th, 2018

Working group report: CP-violation

Christopher Smith

- Outline

I. CP-violation in the SM

II. CP-violation beyond the SM

III. Flavor-blind CP-violation

IV. Conclusion

I. CP-violation in the SM

A. Where does CP-violation come from?

Theoretically: a complex Lagrangian parameter induces CP-violation.

$$\psi_{L,R} \xrightarrow{CP} \psi^\dagger_{L,R}$$

$$\begin{aligned}\mathcal{L}_{\text{int}} &= g\phi\, \psi^\dagger_R \psi_L - m\psi^\dagger_R \psi_L + h.c. \\ &= g\phi\psi^\dagger_R\psi_L - m\psi^\dagger_R\psi_L + g^*\phi\, \psi^\dagger_L\psi_R - m^*\psi^\dagger_L\psi_R\end{aligned}$$

$$CP(\mathcal{L}_{\text{int}}) = g\phi\psi_R\psi^\dagger_L - m\psi_R\psi^\dagger_L + g^*\phi\, \psi_L\psi^\dagger_R - m^*\psi_L\psi^\dagger_R$$

CP-conservation $CP(\mathcal{L}_{\text{int}}) = \mathcal{L}_{\text{int}} \Leftrightarrow \arg(g) = \arg(m) = 0.$

But, not all phases are physical:

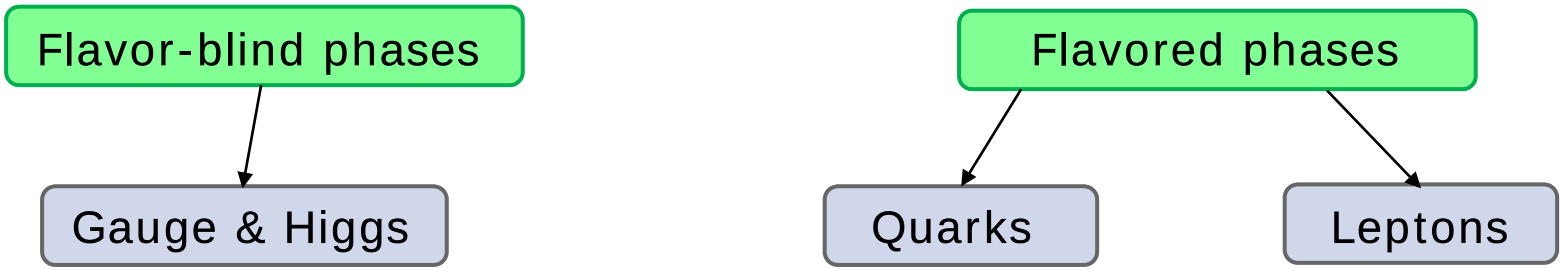
Field redefinitions to absorb as many phases as possible

$$\psi_R \to \psi_R e^{i \arg m},\ \psi_L \to \psi_L$$

Left-over phases are responsible for CPV in observables.

A. Where does CP-violation come from?

In the SM, two types of phases survive to all redefinitions:



B. Flavor-blind phases in the SM

Three CPV terms are present in the SM gauge Lagrangian:

$$\mathcal{L}_{\not{CP}} = \theta_C \frac{\alpha_S}{8\pi} G_{\mu\nu}\tilde{G}^{\mu\nu} + \theta_L \frac{g^2}{16\pi^2} W_{\mu\nu}\tilde{W}^{\mu\nu} + \theta_Y \frac{g'^2}{16\pi^2} B_{\mu\nu}\tilde{B}^{\mu\nu}$$

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When massless, the quarks/leptons have identical gauge interactions

→ flavor symmetry: $G_F = U(3)^5 = U(3)_Q \times U(3)_U \times U(3)_D \times U(3)_L \times U(3)_E$

Example:

$$U_R^I = \begin{pmatrix} u_R \\ c_R \\ t_R \end{pmatrix} \to U_R'^I = \begin{pmatrix} u'_R \\ c'_R \\ t'_R \end{pmatrix} = (g_U)^{IJ} U_R^J \quad , \; g_U^\dagger g_U = 1 :$$

$$\mathcal{L}_{Kin} = \sum_{I=1,2,3} \bar{U}_R^I \, i\not{D} U_R^I \to \sum_{k,I,J,K} \bar{U}_R^J (g_U^\dagger)^{JI} \, i\not{D} (g_U)^{IK} U_R^K = \mathcal{L}_{Kin}$$

B. Flavor-blind phases in the SM

Three additional CPV terms should be present in the SM Lagrangian:

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These U(1)s are chiral hence anomalous:

$$\begin{pmatrix} \partial_\mu J_Q^\mu \\ \partial_\mu J_U^\mu \\ \partial_\mu J_D^\mu \\ \partial_\mu J_L^\mu \\ \partial_\mu J_E^\mu \end{pmatrix} = -\frac{N_f}{16\pi^2} \begin{pmatrix} 1 & 3/2 & 1/6 \\ 1/2 & 0 & 4/3 \\ 1/2 & 0 & 1/3 \\ 0 & 1/2 & 1/2 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} g_s^2 G_{\mu\nu}\tilde{G}^{\mu\nu} \\ g^2 W_{\mu\nu}\tilde{W}^{\mu\nu} \\ g'^2 B_{\mu\nu}\tilde{B}^{\mu\nu} \end{pmatrix}$$

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$$\begin{pmatrix} \partial_\mu J_Y^\mu \\ \partial_\mu J_B^\mu \\ \partial_\mu J_L^\mu \\ \partial_\mu J_{PQ}^\mu \\ \partial_\mu J_E^\mu \end{pmatrix} = -\frac{N_f}{16\pi^2} \begin{pmatrix} 0 & 0 & 0 \\ 0 & 1/2 & -1/2 \\ 0 & 1/2 & -1/2 \\ 1 & 0 & 8/3 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} g_s^2 G_{\mu\nu}\tilde{G}^{\mu\nu} \\ g^2 W_{\mu\nu}\tilde{W}^{\mu\nu} \\ g'^2 B_{\mu\nu}\tilde{B}^{\mu\nu} \end{pmatrix}$$

$U(1)_{B-L}$ and $U(1)_Y$ are anomaly-free.

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→ flavor symmetry: $G_F = U(3)^5 = U(3)_Q \times U(3)_U \times U(3)_D \times U(3)_L \times U(3)_E$

These U(1)s are chiral hence anomalous.

With the appropriate rotations, all three CPV terms are eliminated:

$$\theta_C \to \theta_C - N_f(2\alpha_Q + \alpha_U + \alpha_D)$$

$$\theta_L \to \theta_L - N_f(3\alpha_Q + \alpha_L)$$

$$\theta_Y \to \theta_Y - N_f(1/3\alpha_Q + 8/3\alpha_U + 2/3\alpha_D + \alpha_L + 2\alpha_E)$$

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When massive, the $U(3)^5$ symmetry is broken by the Yukawa couplings.

We must require the quark/lepton masses to be real!

= Three $U(1)$ are fixed to get to $v\mathrm{Y}_u = m_u V_{CKM}$, $v\mathrm{Y}_{d,e} = m_{d,e}$.

Not enough freedom remains to get rid of all three CPV interactions:

$$\theta_C \to \theta_C - \arg\det \mathrm{Y}_u - \arg\det \mathrm{Y}_d$$

$$\theta_L \to \theta_L - N_f(3\alpha_Q + \alpha_L)$$

$$\theta_Y \to \theta_Y + N_f(3\alpha_Q + \alpha_L) - \frac{8}{3}\arg\det \mathrm{Y}_u - \frac{2}{3}\arg\det \mathrm{Y}_d - 2\arg\det \mathrm{Y}_e$$

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Cannot be removed: Strong CP puzzle.

Removed thanks to $U(1)_{B+L}$ (choice for $3\alpha_Q + \alpha_L$)

Removed by partial integration.

Not enough freedom remains to get rid of all three CPV interactions:

$$\theta_C \to \theta_C - \arg\det \mathbf{Y}_u - \arg\det \mathbf{Y}_d$$

$$\theta_L \to \theta_L - N_f(3\alpha_Q + \alpha_L)$$

$$\theta_Y \to \theta_Y + N_f(3\alpha_Q + \alpha_L) - \frac{8}{3}\arg\det \mathbf{Y}_u - \frac{2}{3}\arg\det \mathbf{Y}_d - 2\arg\det \mathbf{Y}_e$$

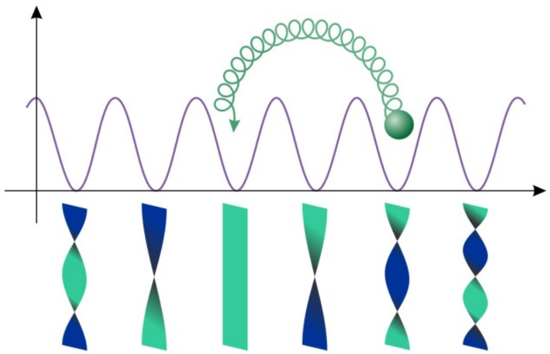
B. Flavor-blind phases in the SM

Why is this strong CP-violation term so puzzling?

$$\mathcal{L}_{\not{CP}} = (\theta_C - \arg\det Y_u - \arg\det Y_d)\frac{\alpha_S}{8\pi} G_{\mu\nu}\tilde{G}^{\mu\nu}$$

QCD has a non-trivial topology:

Explains the large η' mass ←



Violates time-reversal

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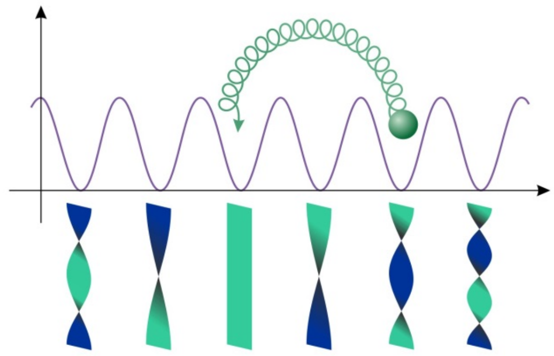

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Yukawa couplings to the Higgs:

We know they are complex.

$\delta_{CKM} \neq 0$

from K and B physics

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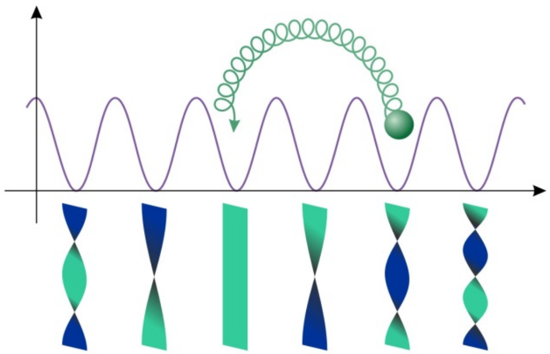

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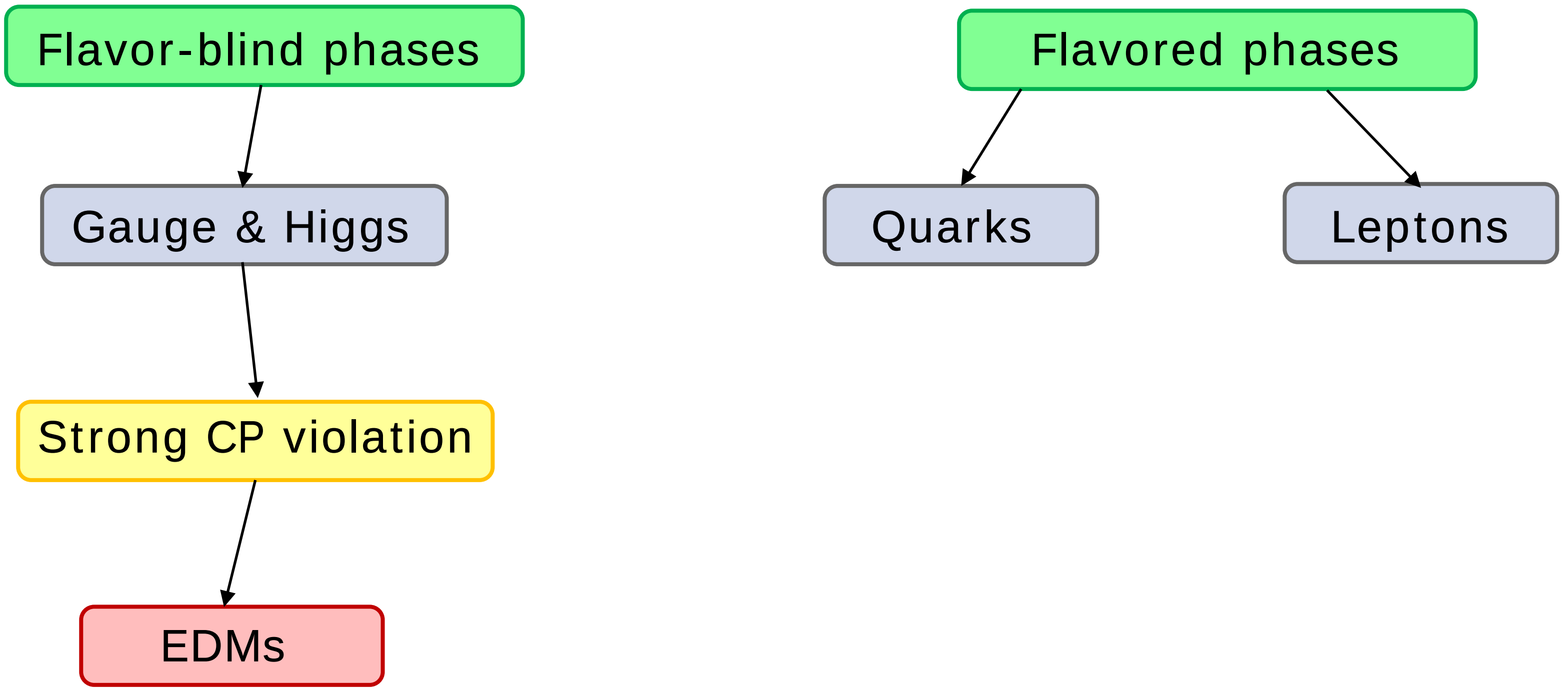
Strong CP puzzle

Neutron EDM implies $(\theta_C - \arg\det Y_u - \arg\det Y_d) < 10^{-10}$!!!

B. Flavor-blind phases in the SM

In the SM, two types of phases:

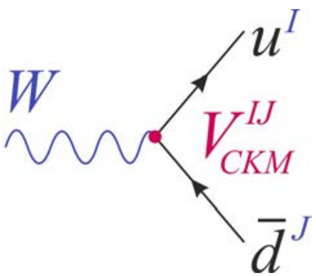


C. Flavored phases in the SM

The U(3) symmetry of the gauge sector permits to rotate to:

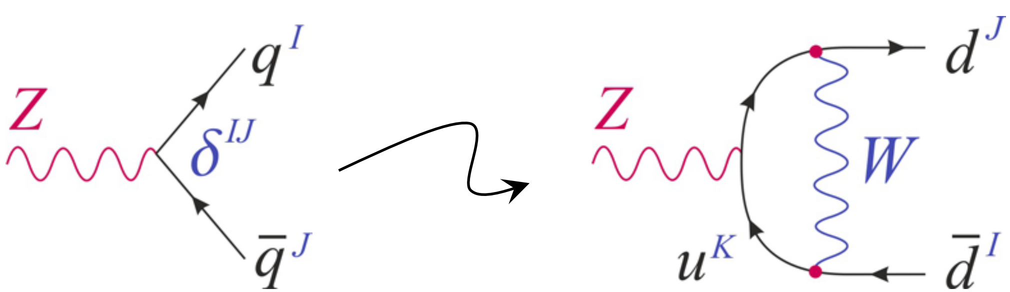
$$\mathcal{L} = -U Y_u Q H - D Y_d Q H^C - E Y_e L H^C \text{ with } v Y_u = m_u V_{CKM}\,,\; v Y_{d,e} = m_{d,e}\,.$$

CP-violation hidden in the CKM matrix → Flavor transitions



$$= \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1 & 10^{-1} & 10^{-3} \\ 10^{-1} & 1 & 10^{-2} \\ 10^{-3} & 10^{-2} & 1 \end{pmatrix} + \mathcal{O}(10^{-4})$$

Interplay with FCNC, both CPV and CPC



Loop-level only

GIM suppressed

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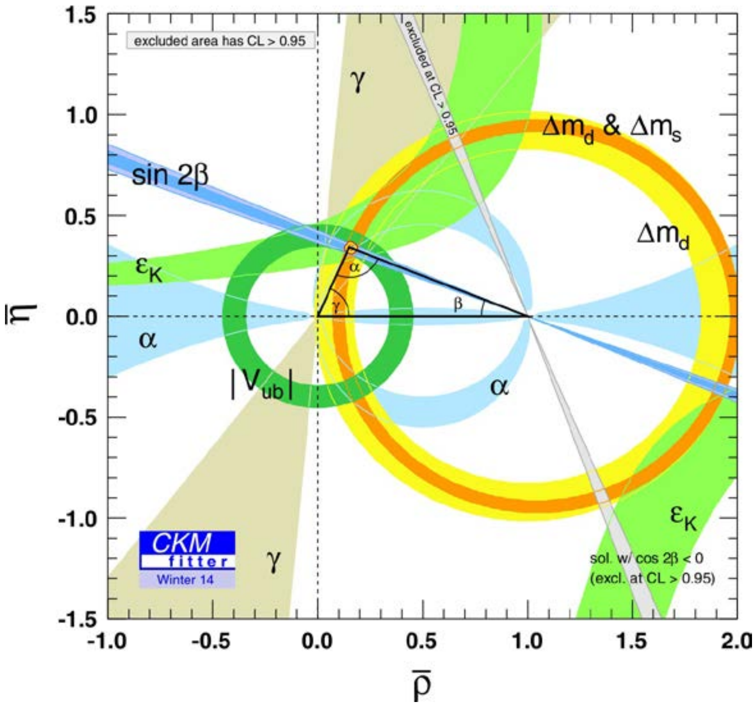
The global CPV & CPC picture in the SM is very constrained:



Need for global fit to combine all the information and test the SM

Sometimes, CPV has the advantage of smaller theory error.

C. Flavored phases in the SM

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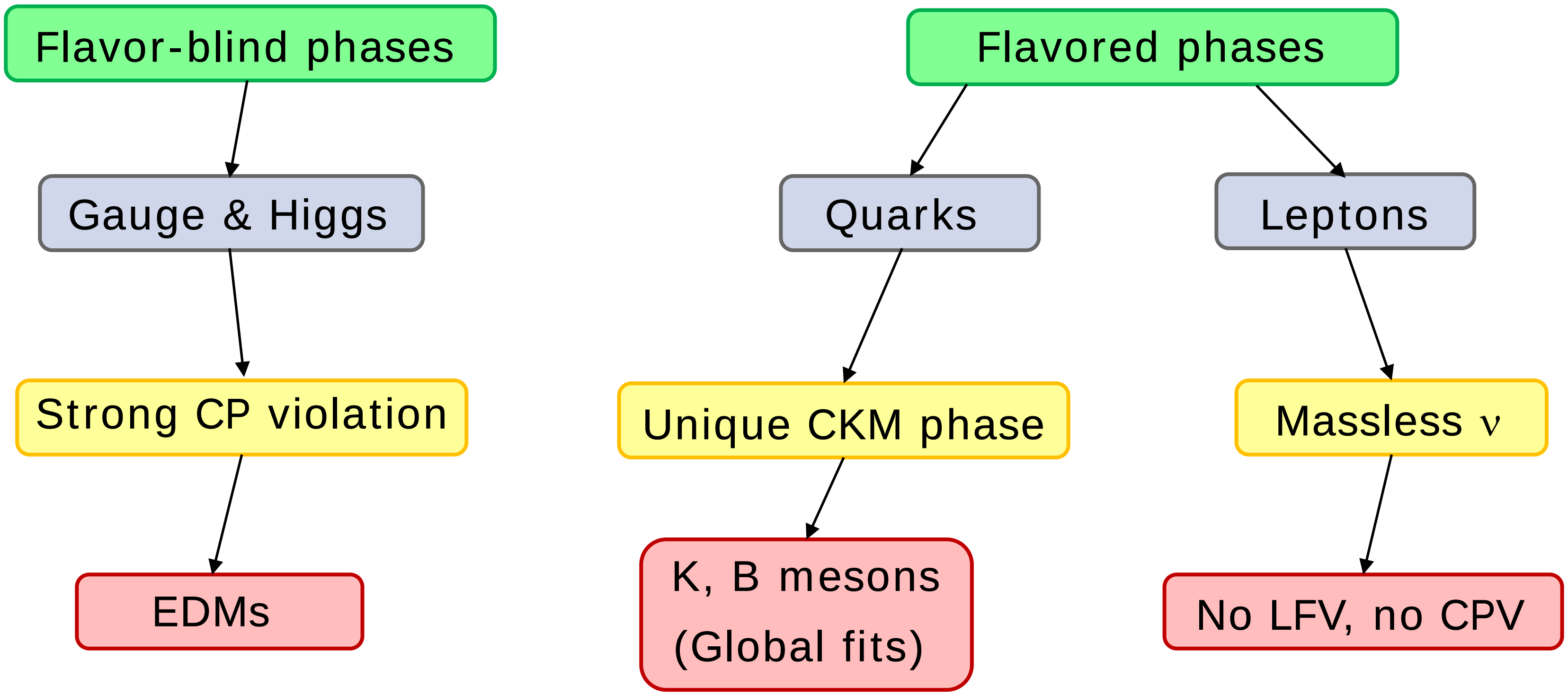
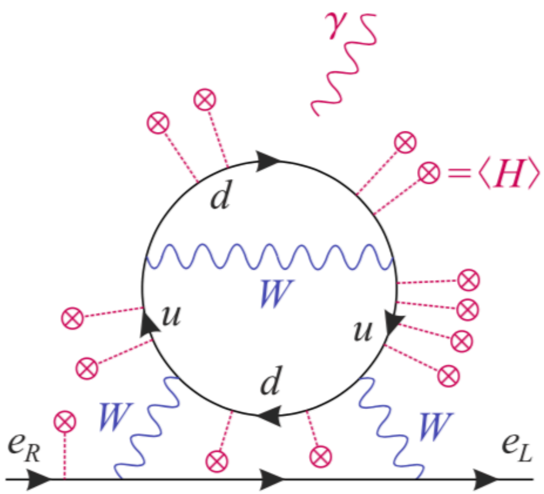


D. From flavored to flavorless phases in the SM

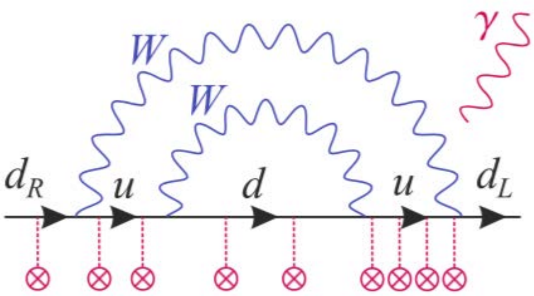
Smith, Touati, '17

CKM-induced lepton EDM	CKM-induced quark EDM



$$\propto \det\left[Y_u^\dagger Y_u, Y_d^\dagger Y_d\right] \sim 10^{-22}$$

$$\propto \mathrm{Im}(V_{us}V_{cb}V_{ub}^*V_{cs}^*)$$



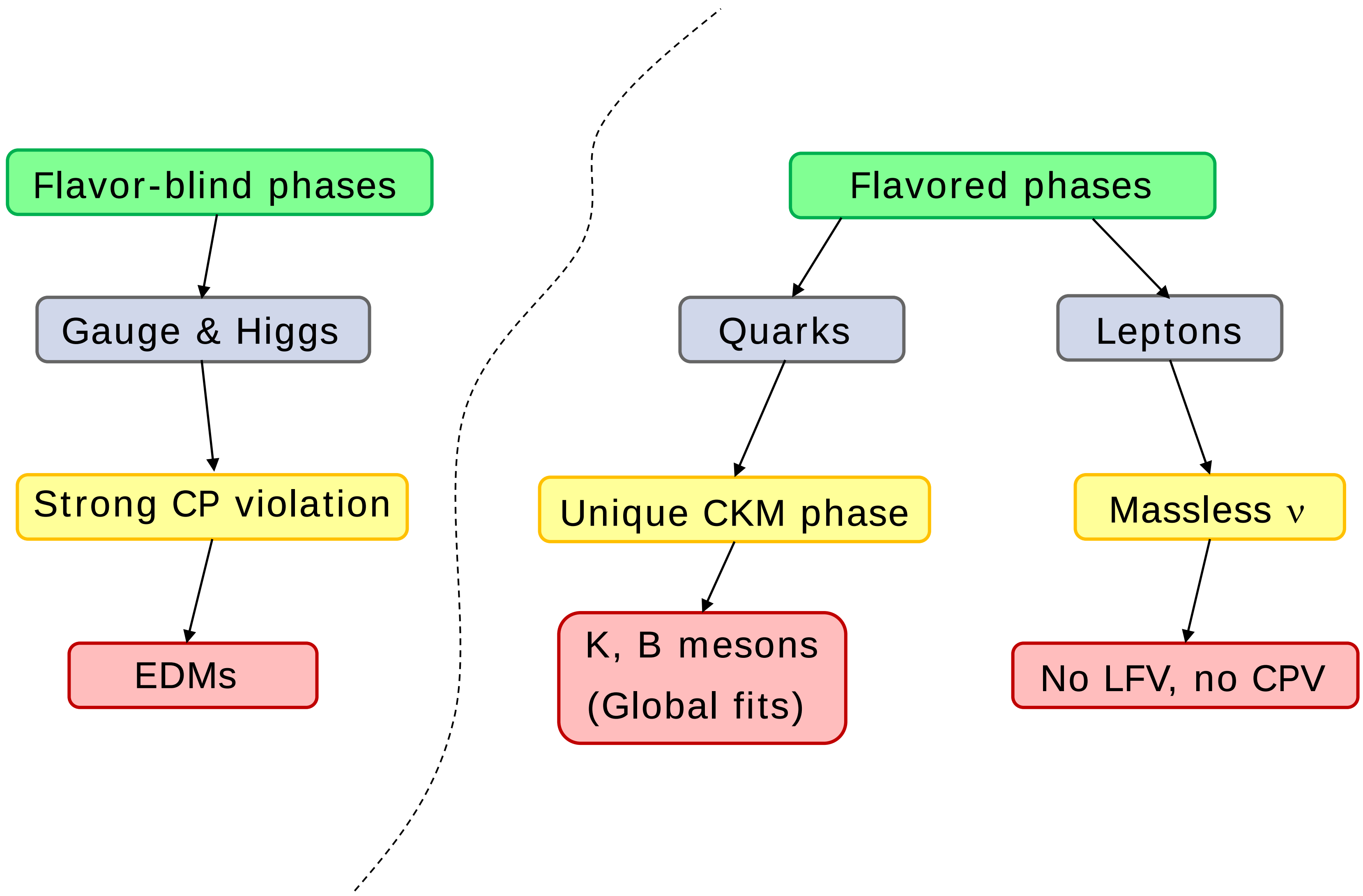
$$\propto \mathrm{Im}\left[Y_u^\dagger Y_u, Y_u^\dagger Y_u Y_d^\dagger Y_d Y_u^\dagger Y_u\right]^{dd} \sim 10^{-12}$$

$$\propto \mathrm{Im}(V_{us}V_{cb}V_{ub}^*V_{cs}^*)$$

The induced EDMs are way beyond experimental reach.

The SM dynamics effectively shields strong CPV from weak CPV.

D. CP-violating phases in the SM



II. CP-violation beyond the SM

A. CP-violating phases beyond the SM

Lagrangian contains new particles & couplings

In general, number of couplings increases a lot!
Many of them are physically complex.

The accidents of the SM do not survive to NP.

E.g.: Seesaw: Introducing ν_R with a Majorana mass term

6 new CPV phases at the low-scale.

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E.g.: THDM: CPV in the scalar potential

Spontaneous CPV when the Higgses acquire their VEVs

Additional CPV phases in the new Yukawa couplings

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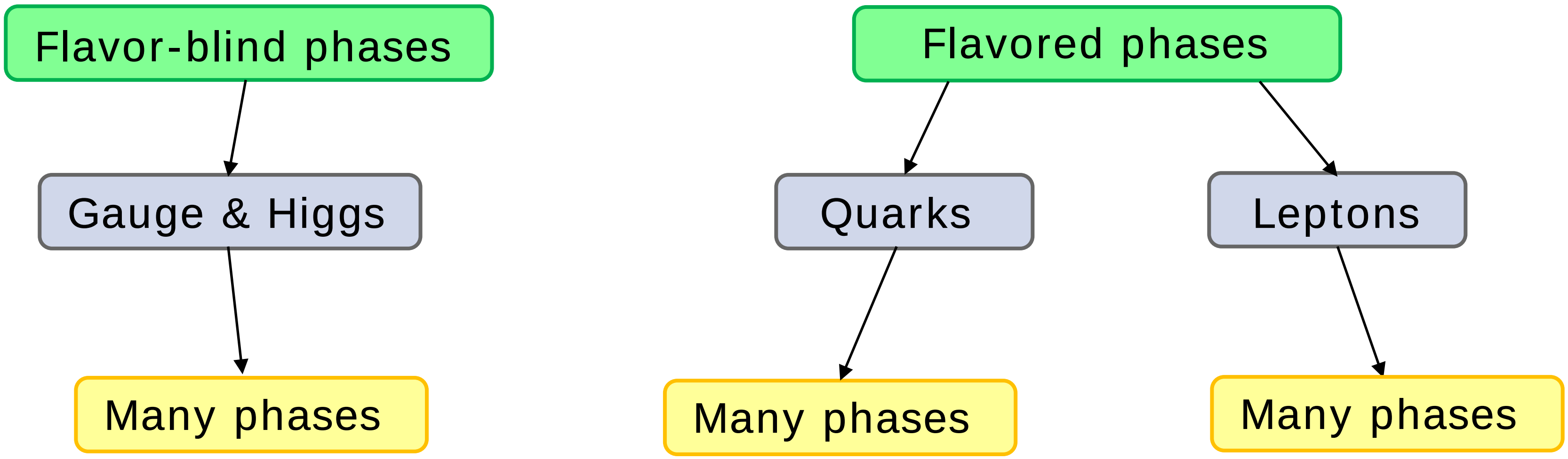
Additional CPV phases in the new Yukawa couplings

E.g.: SUSY: 3 new CPV phases in the gauge/scalar sector

40 new CPV in the squark/slepton sectors

A. CP-violating phases beyond the SM

Still two types of phases:



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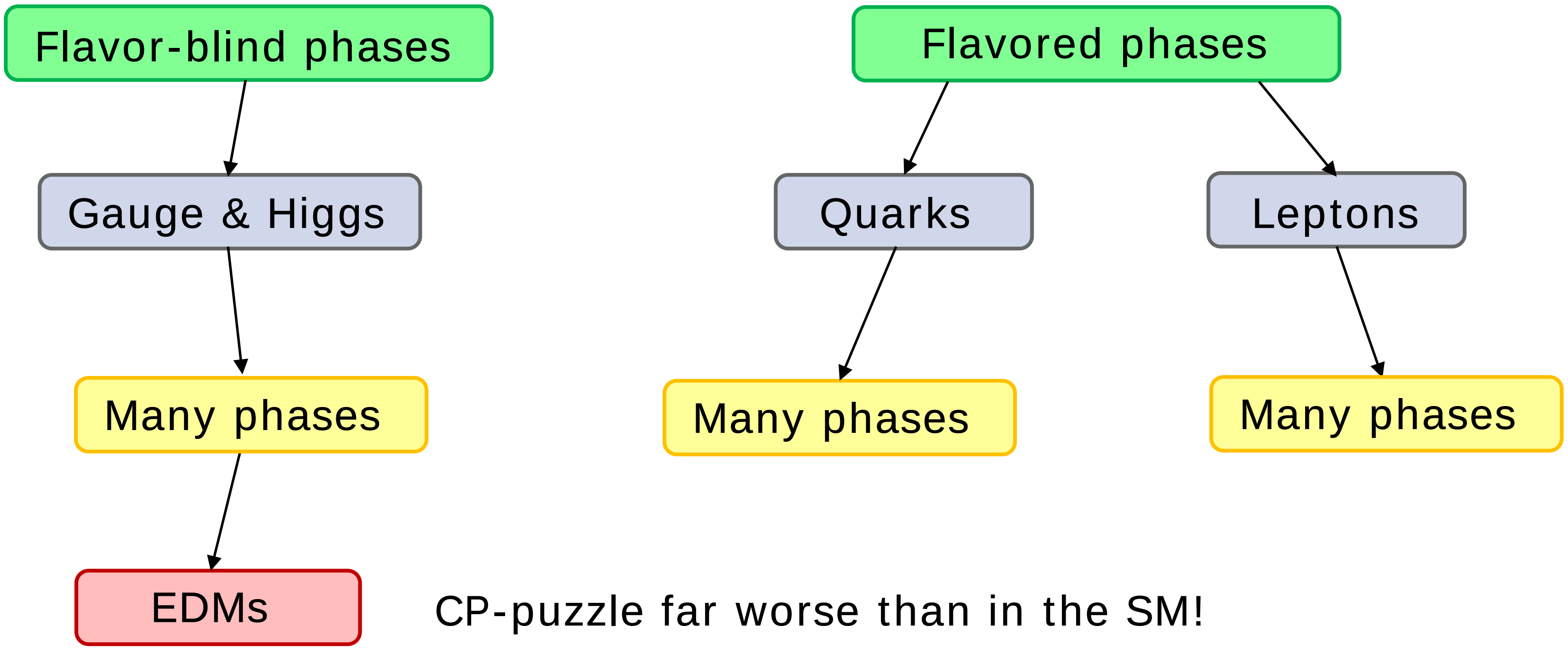


CP-puzzle far worse than in the SM!

B. Quark sector

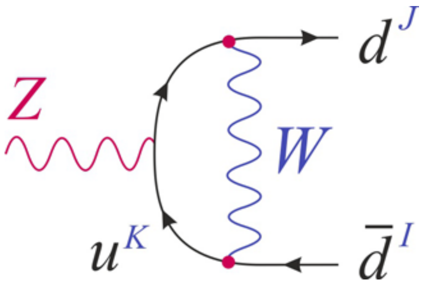
Decoupling theorem:

At low energy, the effects of new heavy particles are either

- Absorbed as unobservable shifts of the SM parameters,
- Encoded into higher dimensional effective operators.

$$\mathcal{L}_{tot} = \mathcal{L}_{SM} + \sum_{i,d>4} \frac{\mathcal{C}_i}{\Lambda^{d-4}} \mathcal{Q}_i$$

Example: The Z penguin



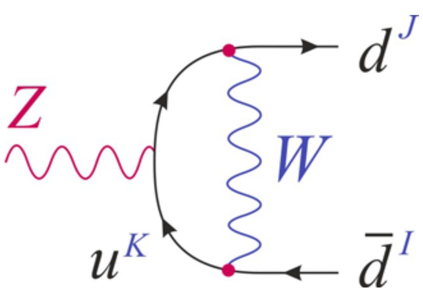
$$\mathcal{O}_Z \sim \frac{1}{\Lambda^2} \times \mathcal{C}^{IJ} \times \bar{Q}^I \gamma^\mu Q^J H^\dagger D_\mu H$$

$$\mathcal{C}_{SM}^{IJ} \sim (\mathrm{Y}_u^\dagger \mathrm{Y}_u)^{IJ} \sim \frac{m_t^2}{v^2} V_{tI}^\dagger V_{tJ}$$

B. Quark sector

Current bounds on Λ (in TeV): The Z penguin

$\mathcal{C}^{IJ}$	1	$g^2/4\pi$	$V_{tI}^\dagger V_{tJ}$	$V_{tI}^\dagger V_{tJ}\, g^2/4\pi$
$B_s \to \mu^+\mu^-$	12	2.2	2.5	0.45
$B_d \to \mu^+\mu^-$	17	3	1.5	0.27
$K \to \pi\nu\bar{\nu}$	100	18	1.8	0.33



$$\mathcal{O}_Z \sim \frac{1}{\Lambda^2} \times \mathcal{C}^{IJ} \times \bar{Q}^I \gamma^\mu Q^J H^\dagger D_\mu H$$

$$\mathcal{C}_{SM}^{IJ} \sim (Y_u^\dagger Y_u)^{IJ} \sim \frac{m_t^2}{v^2} V_{tI}^\dagger V_{tJ}$$

$b \to s$	$b \to d$	$s \to d$
0.04	0.008	0.0003

B. Quark sector

Hierarchy puzzle = Stability of the EW scale:

→ New physics must be light.

Flavor puzzles = non-observation of new effects at low energy:

→ New physics must be very heavy.

OR

→ New physics must have tiny, fine-tuned couplings.

The SM flavor sector is full of «tiny» parameters.

New Physics just needs to be approximately aligned with the SM.

To do this consistently: Minimal Flavor Violation.

B. Quark sector – Minimal Flavor Violation

FCNC : Puzzles are automatically solved.

$$\frac{1}{\Lambda^2} \times \mathcal{C}^{IJ} \times \bar{Q}^I \gamma^\mu Q^J H^\dagger D_\mu H \quad \rightarrow \quad \mathcal{C} = a_0 1 + a_1 Y_u^\dagger Y_u + a_2 Y_d^\dagger Y_d + \ldots$$

$$\mathcal{C} \sim \left(\begin{pmatrix} 1 & 10^{-4} & 10^{-3} \\ 10^{-4} & 1 & 10^{-2} \\ 10^{-3} & 10^{-2} & 1 \end{pmatrix} + i \begin{pmatrix} 0 & 10^{-4} & 10^{-3} \\ 10^{-4} & 0 & 10^{-4} \\ 10^{-3} & 10^{-4} & 0 \end{pmatrix} \right)$$

$\mathcal{C}^{IJ}$	1	$V_{tI}^\dagger V_{tJ}$
$B_s \rightarrow \mu^+\mu^-$	12	2.5
$B_d \rightarrow \mu^+\mu^-$	17	1.5
$K \rightarrow \pi\nu\bar{\nu}$	100	1.8

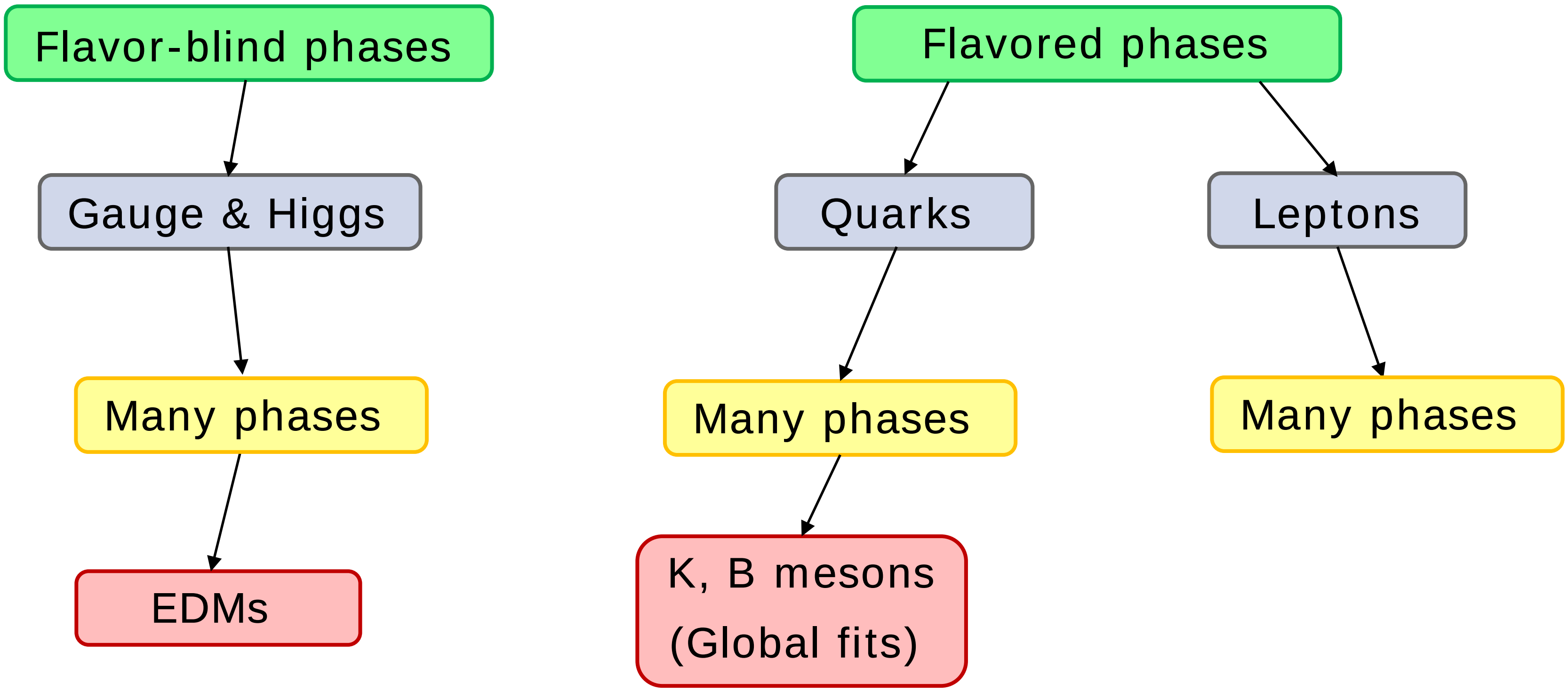
What is important is the pattern of CPC and CPV, similar as in the SM.

New Physics effects are not large → Precision needed!

Global fits to try to evidence some deviations.

B. Quark sector – Minimal Flavor Violation

Still two types of phases:



C. Lepton sector – Minimal Flavor Violation?

Neutrino masses require some new flavor structures.

Cirigliano,Grinstein
Isidori,Wise '05

For example, with a seesaw mechanism:

$$\mathrm{Y}_e\,,\qquad \mathrm{Y}_\nu^\dagger \mathrm{Y}_\nu\,,\qquad \Upsilon_\nu \equiv \mathrm{Y}_\nu^T \mathrm{M}^{-1} \mathrm{Y}_\nu\,,\qquad \mathrm{Y}_\nu^\dagger \mathrm{M}^{-1*} \mathrm{M}^{-1} \mathrm{Y}_\nu\,,\quad \ldots$$

Lepton masses:

$$v_d \mathrm{Y}_e = \mathrm{m}_e$$

Neutrino masses:

$$v_u^2 \mathrm{Y}_\nu^T \mathrm{M}^{-1} \mathrm{Y}_\nu = U^* \mathrm{m}_\nu U^\dagger$$

Not completely fixed (we take $\mathrm{M} = M_R \mathbf{1}$):

$$v_u^2 \mathrm{Y}_\nu^\dagger \mathrm{Y}_\nu = M_R U^* \mathrm{m}_\nu^{1/2} e^{2i\Phi} \mathrm{m}_\nu^{1/2} U^\dagger\,,\quad \Phi^{IJ} = \varepsilon^{IJK} \phi_K$$

Casas,Ibarra '01,
Pascoli,Petcov,
Yaguna '03,...

In that case, lepton universality «quite» automatic:

$$\mathcal{C}^{IJ} \times L^I \gamma^\mu L^J \times (\ldots) \;\rightarrow\; \mathcal{C} = a_0 \mathbf{1} + a_1 \mathrm{Y}_\nu^\dagger \mathrm{Y}_\nu + a_2 \mathrm{Y}_e^\dagger \mathrm{Y}_e + \ldots$$

C. Lepton sector – Minimal Flavor Violation?

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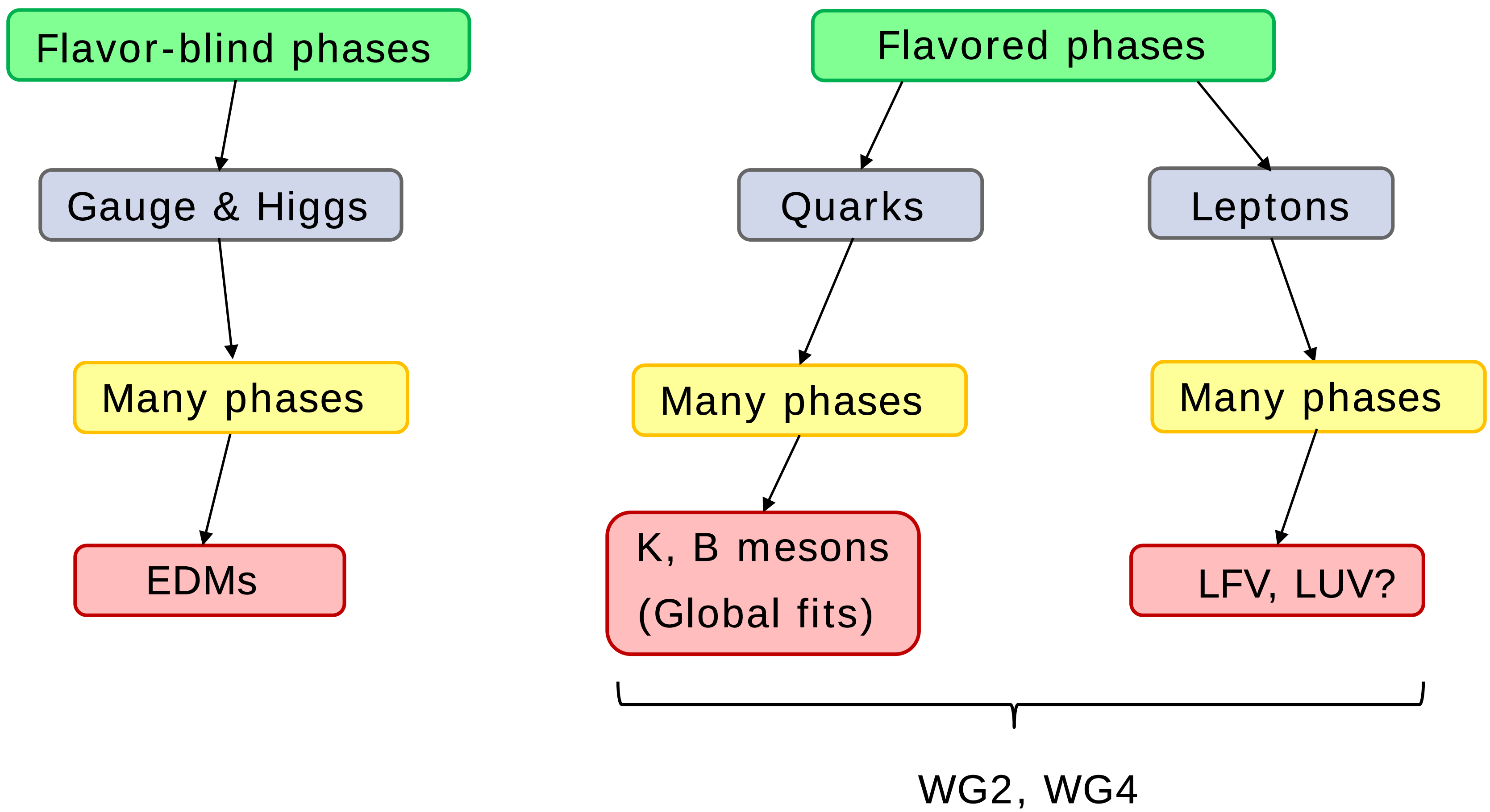

D. Flavor-blind CP-violation from flavored phases – quark sector

EDM : What happens with Minimal Flavor Violation?

$$H_{eff} = C^{IJ}\,\bar{\psi}_L^I \sigma_{\mu\nu} \psi_R^J F^{\mu\nu} + C^{IJ*}\,\bar{\psi}_R^J \sigma_{\mu\nu} \psi_L^I F^{\mu\nu}$$

$I = J$:

$$H_{eff} = \mathrm{Re}\,C\,\bar{\psi}\sigma_{\mu\nu}\psi F^{\mu\nu} + i\,\mathrm{Im}\,C\,\bar{\psi}\sigma_{\mu\nu}\gamma_5\psi F^{\mu\nu}$$

$$\mathrm{Re}\,C \equiv e\frac{a}{4m}, \qquad \mathrm{Im}\,C \equiv \frac{d}{2}$$

$I \neq J$:

$$B(\psi^I \to \psi^J \gamma) \sim \left|C^{IJ}\right|^2$$

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$$H_{eff} = C^{IJ}\,\bar{\psi}_L^I \sigma_{\mu\nu} \psi_R^J F^{\mu\nu} + C^{IJ*}\,\bar{\psi}_R^J \sigma_{\mu\nu} \psi_L^I F^{\mu\nu}$$

$I = J$

$$H_{eff} = \text{Re}\,C\,\bar{\psi}\sigma_{\mu\nu}\psi F^{\mu\nu} + i\,\text{Im}\,C\,\bar{\psi}\sigma_{\mu\nu}\gamma_5\psi F^{\mu\nu}$$

$$\text{Re}\,C \equiv e\frac{a}{4m}, \qquad \text{Im}\,C \equiv \frac{d}{2}$$

$I \neq J$

$$B(\psi^I \to \psi^J \gamma) \sim \left|C^{IJ}\right|^2$$

Flavored CP-violating phases under control: Mercolli, CS '09

$$\text{Im}\,\mathcal{C}^{II} = \text{Y}_d\left(\text{Im}\,a_0 1 + \text{Im}\,a_1 (\text{Y}_u^\dagger \text{Y}_u)^{II} + \text{Im}\,a_2 (\text{Y}_d^\dagger \text{Y}_d)^{II} + \ldots\right)$$

$$\text{Im}\,a_0 + a_0' \det\left[\text{Y}_u^\dagger \text{Y}_u, \text{Y}_d^\dagger \text{Y}_d\right]$$

Flavor blind: unconstrained

Flavored: suppressed

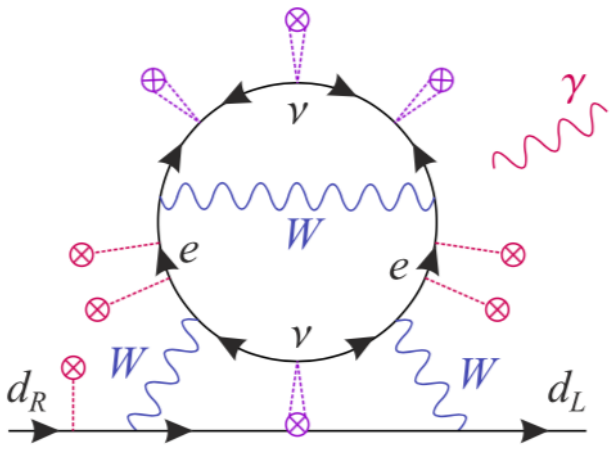
MFV able to shield flavor-blind CPV from flavored CPV.

D. Flavor-blind CP-violation from flavored phases – lepton sector

Smith, Touati, '17

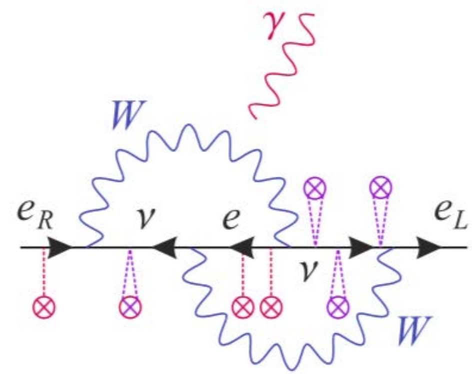
EDM : What happens with new flavor structures?

Majorana-induced quark EDM



$$\propto \mathrm{Im}\left[\Upsilon_\nu^\dagger Y_e^\dagger Y_e \Upsilon_\nu \cdot Y_e^\dagger Y_e \cdot \Upsilon_\nu^\dagger \Upsilon_\nu\right]$$

Majorana-induced lepton EDM



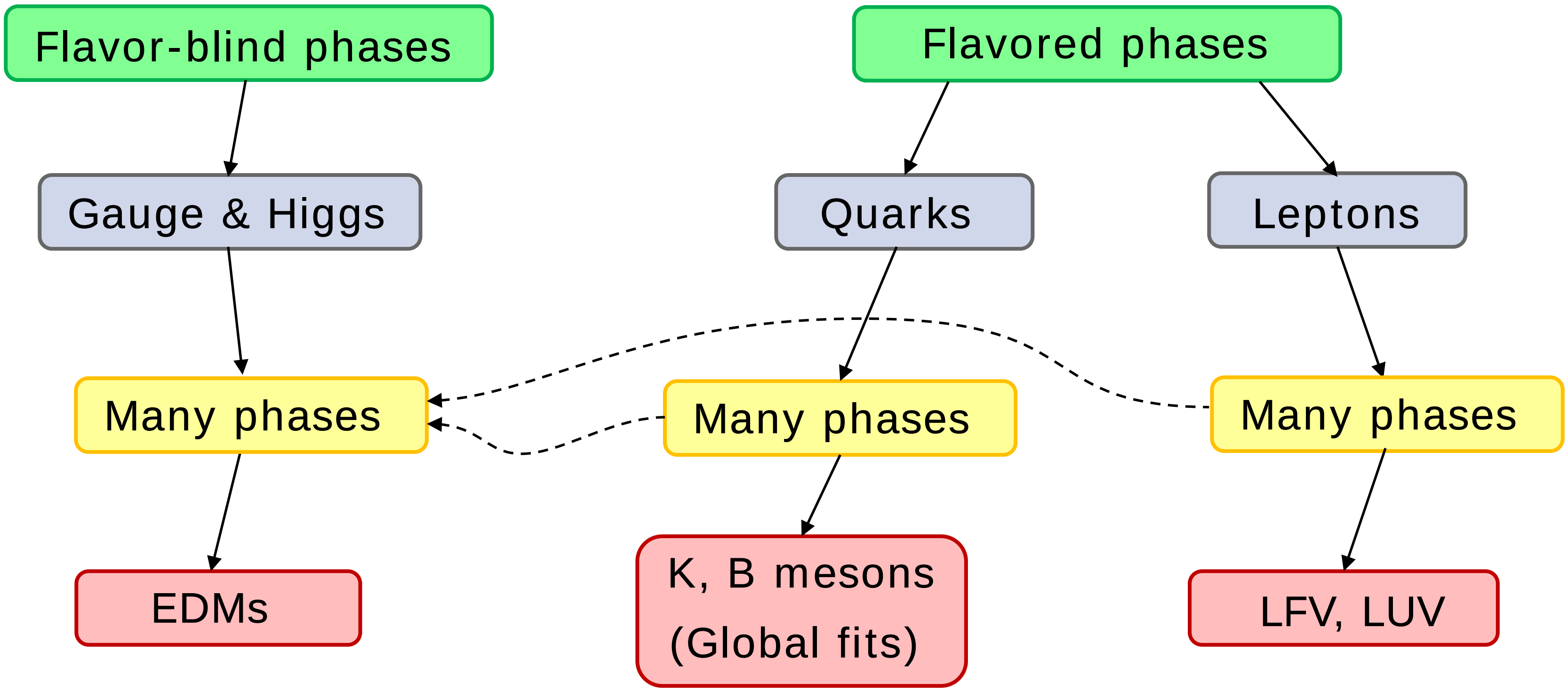
$$\propto \mathrm{Im}\left[\Upsilon_\nu^\dagger \Upsilon_\nu,\ \Upsilon_\nu^\dagger (Y_e^\dagger Y_e)^T \Upsilon_\nu\right]^{ee}$$

Both could be sizeable in a seesaw Type II scenario.

Flavor-blind CPV not always well protected against leptonic phases.

E. CP-violation beyond the SM

Still two types of phases:



III. Flavor-blind CP violation

A. The axionic solutions

$$\mathcal{L}_{axion} = -\frac{1}{4}G_{\mu\nu}G^{\mu\nu} - \frac{3g^2}{32\pi^2}\theta_S G_{\mu\nu}\tilde{G}^{\mu\nu} + \bar{\psi}_{L,R} i\not{D}\psi_{L,R} + y_i \bar{\psi}_L \psi_R H_i + V(H_i)$$

Step 1: Invariant under some global U(1) symmetry.

Spontaneously broken by the Higgses VEVs.

One massless goldstone boson, $\langle 0 | J^\mu | a(p) \rangle = i v p^\mu$.

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Step 1: Invariant under some global U(1) symmetry.

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Step 2: Design $\mathcal{L}_{axion}$ such that $Q(\psi_L) \neq Q(\psi_R)$

This makes the symmetry anomalous: $\partial_\mu J^\mu \sim G_{\mu\nu} \tilde{G}^{\mu\nu}$

Net effect: $\mathcal{L}_{axion} = \mathcal{L}_{QCD} + \frac{1}{v} a G_{\mu\nu} \tilde{G}^{\mu\nu} + \ldots$

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One massless goldstone boson, $\langle 0 | J^\mu | a(p) \rangle = ivp^\mu$.

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Net effect: $\mathcal{L}_{axion} = \mathcal{L}_{QCD} + \frac{1}{v} a G_{\mu\nu}\tilde{G}^{\mu\nu} + \ldots$

Step 3: Non-perturbative QCD effects induce

$$\mathcal{L}_{axion} \to \mathcal{L}_{ChPT}(\partial_\mu a, \pi, \eta, \eta', \ldots) + V_{eff}(\theta_S + a/v, \pi, \eta, \ldots)$$

Miminum at $\theta_S + \langle a \rangle / v = 0$: Strong CP relaxes to zero!

B. The axionic solutions

Mini-school & Workshop held at the LPSC in May 2018
https://indico.cern.ch/event/703481/

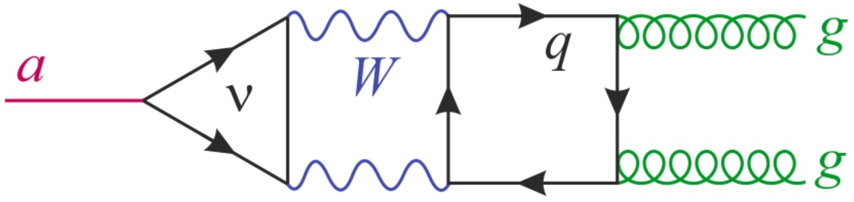
Experimentally: Many new searches are planned,

True axions or ALPs,

« Particle » or « astroparticle » axions.

Theoretically: Axions as a solution for something else?

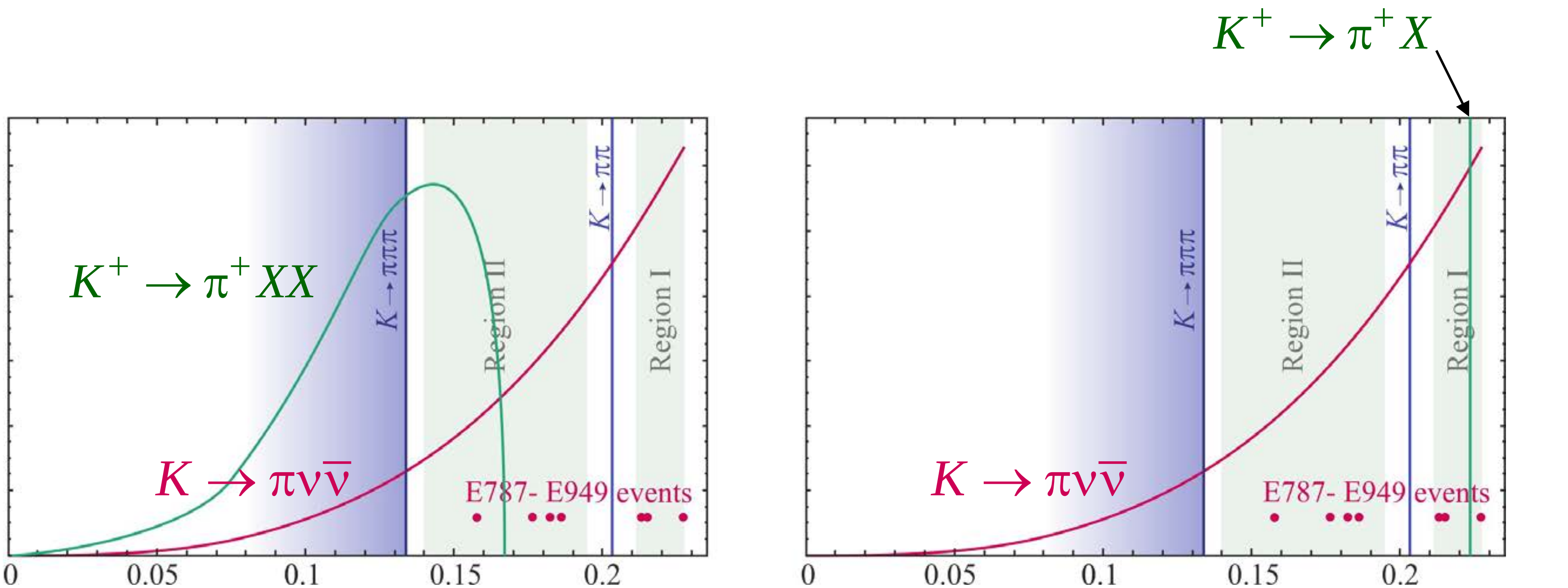
E.g., axion = majoron?



Interplay with the many seaches for new light particles

C. Looking for light particles in flavored decays?

Invisible particles have the same signature as neutrinos!



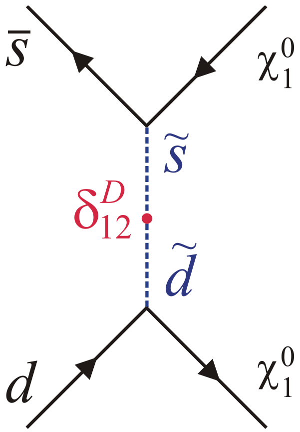
For both K and B decays:

- Cuts are usually introduced to reduce BG.
- SM differential rate may be implicit in MC.
- SM differential rate may be implicit in total rates.

D. Example 1: Very light neutralinos

Dreiner et al '09

Beyond MFV, the flavor-breaking comes from squark mixings.



Effective couplings:

$\bar{s}\gamma^\mu(1\pm\gamma_5)d \otimes \bar{\chi}\gamma_\mu\gamma_5\chi$, tuned by δ_{LL},δ_{RR} .

$\bar{s}(1\pm\gamma_5)d \otimes \bar{\chi}(1\pm\gamma_5)\chi$, tuned by δ_{LR} .

D. Example 1: Very light neutralinos

Dreiner et al ‘09

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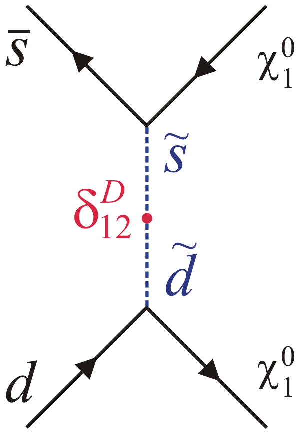
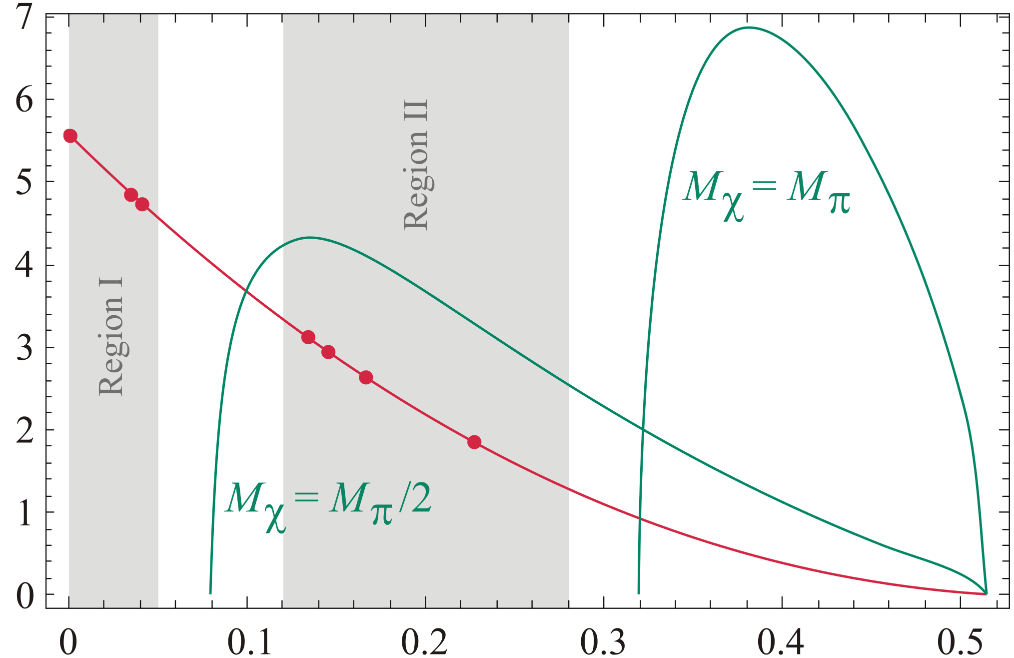


Effective couplings: $\bar{s}\gamma^\mu(1\pm\gamma_5)d \otimes \bar{\chi}\gamma_\mu\gamma_5\chi$

$\bar{s}(1\pm\gamma_5)d \otimes \bar{\chi}(1\pm\gamma_5)\chi$

$K^+ \to \pi^+\chi_1^0\chi_1^0$



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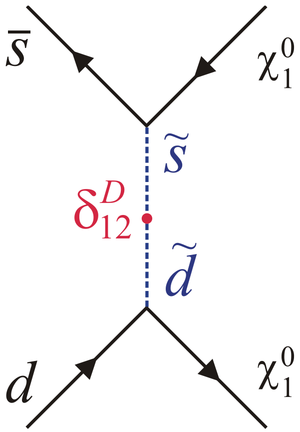

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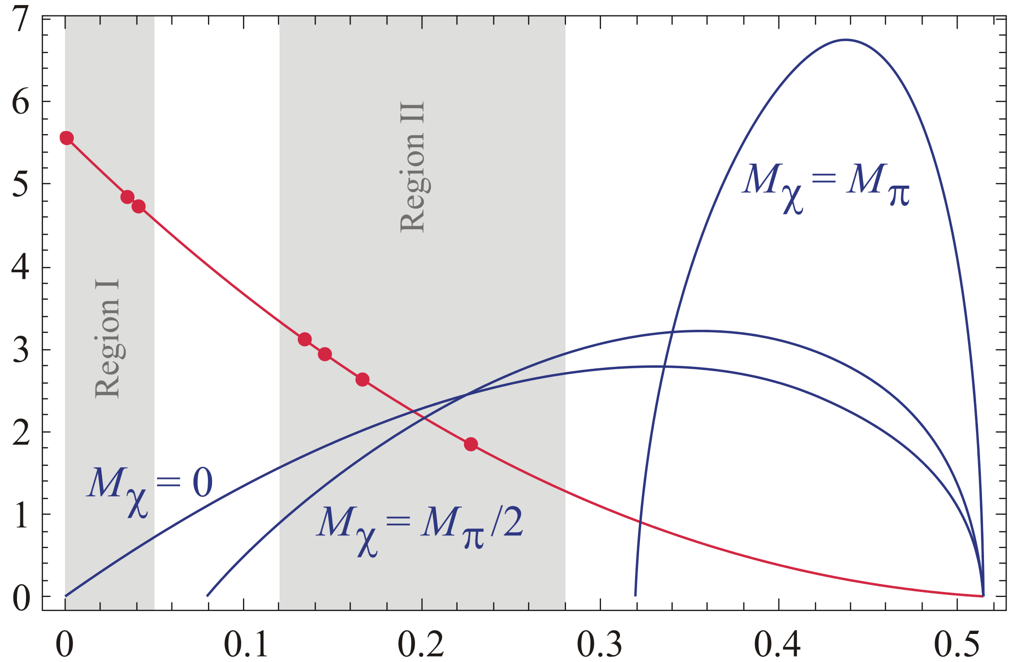

E. Example 2: Weakly-coupled new photon

Kamenik,CS, '12

$$\mathcal{L}_{\text{int}} = e' A'_\mu \left(\frac{2}{3} \bar{u} \gamma^\mu u - \frac{1}{3} \bar{d} \gamma^\mu d - \frac{1}{3} \bar{s} \gamma^\mu s \right)$$

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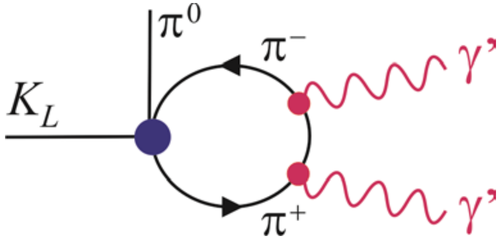


Problem 1: The EW transition strongly suppresses the rate.

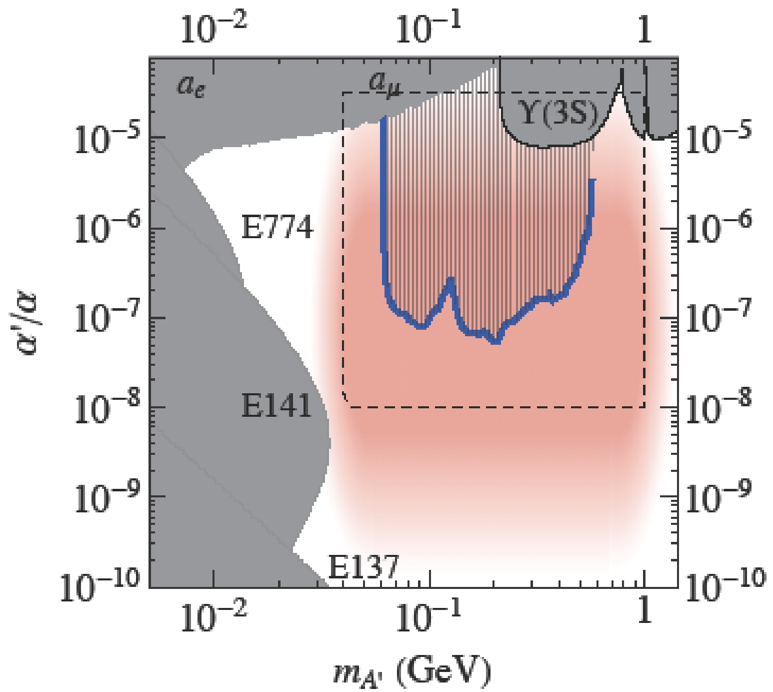
$$Br(K_L \to \pi^0 \gamma\gamma)^{\text{exp}} = 1.273(34) \times 10^{-6}$$

$$\to Br(K_L \to \pi^0 \gamma' \gamma') \approx \frac{\alpha'^2}{\alpha^2} \times 10^{-6}$$

A bound in the 10^{-12} range means

$$\alpha' / \alpha < 10^{-3} \; ,$$

which is already excluded...



From Essig et al, ArXiv:1001.2557

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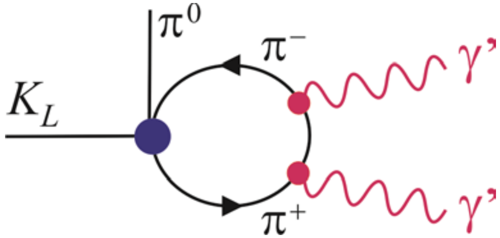
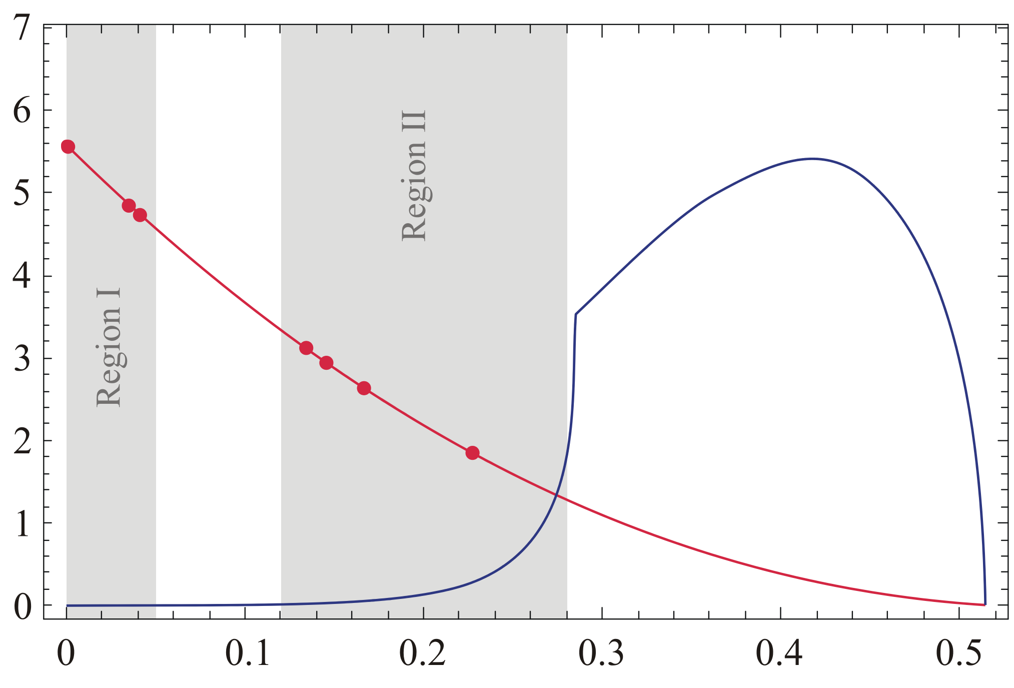


Problem 2: The LD dynamics strongly suppresses the rate below 2π.

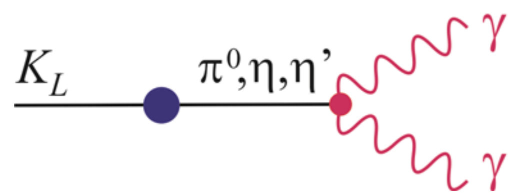


So there is very little sensitivity, no matter the mass of γ'.

E. Example 2: Weakly-coupled new photon

Kamenik,CS, ‘12

$$\mathcal{L}_{\rm int} = e' A'_\mu \left(\frac{2}{3} \bar{u} \gamma^\mu u - \frac{1}{3} \bar{d} \gamma^\mu d - \frac{1}{3} \bar{s} \gamma^\mu s \right)$$



Solution: Look for different final states! The most promising is

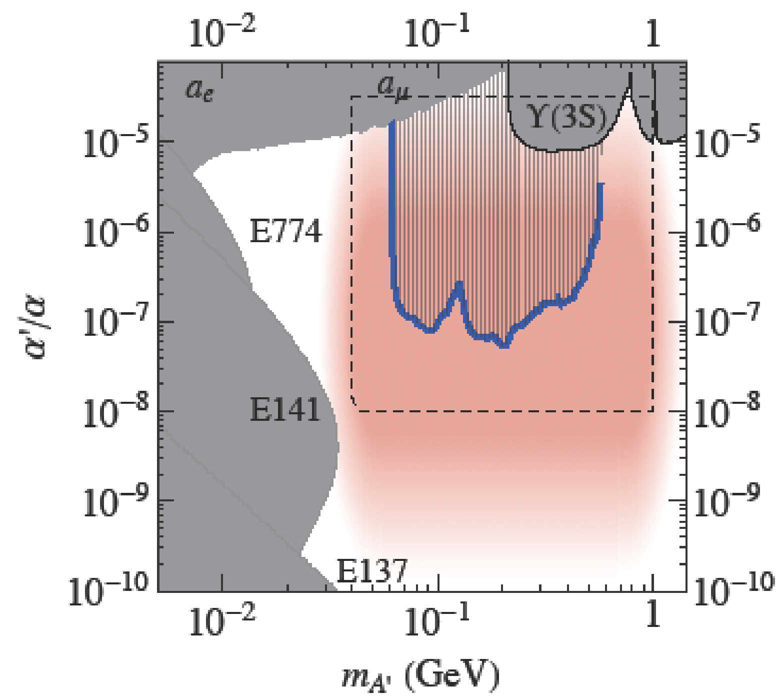
$$Br(K_L \to \gamma\gamma)^{\rm exp} = 5.47(4) \times 10^{-4}$$

$$\to Br(K_L \to \gamma\gamma') \approx \frac{\alpha'}{\alpha} \times 10^{-4}$$

A bound in the 10^{-12} range means

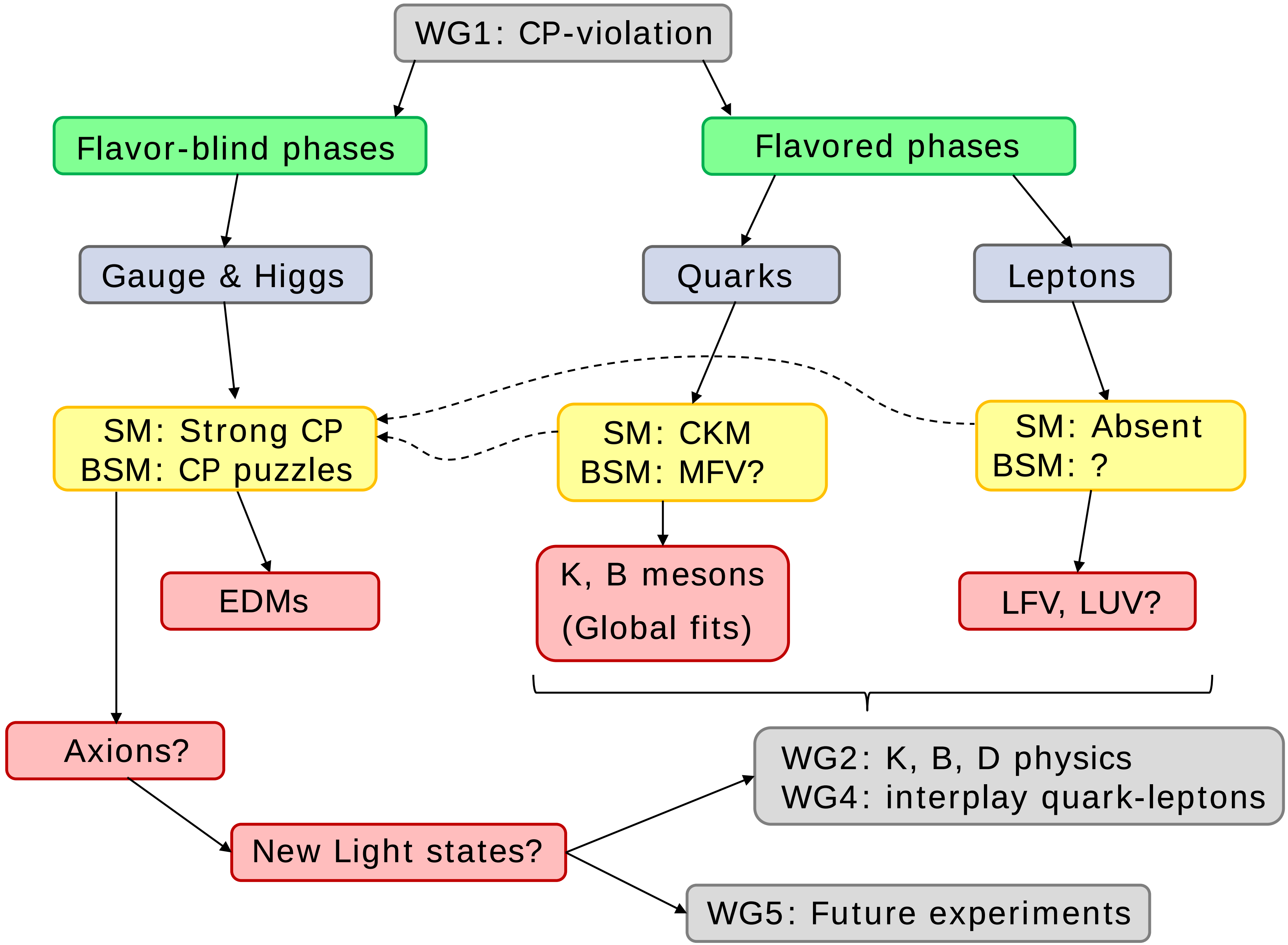
$$\alpha'/\alpha < 10^{-8} ,$$

which would be highly competitive!



(Note: $K_L \to \pi^0 \nu \bar{\nu}$ requires excellent photon capabilities)

Conclusion


WG1: CP-violation
Flavor-blind phases
Flavored phases
Gauge & Higgs
Quarks
Leptons
SM: Strong CP
BSM: CP puzzles
SM: CKM
BSM: MFV?
SM: Absent
BSM: ?
EDMs
K, B mesons
(Global fits)
LFV, LUV?
Axions?
New Light states?
WG2: K, B, D physics
WG4: interplay quark-leptons
WG5: Future experiments