Testable Axion-Like Particles in the Minimal Linear σ Model

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Based on J. Alonso-González, L. Merlo, F. Pobbe, S. Rigolin and O. Sumensari,
"Testable Axion-Like Particles in the Minimal Linear σ Model", arXiv:1807.08643 [hep-ph]

1. Fine-Tuning

~ Symmetries allow a term like: $\lambda_{s\phi}(s^*s)(\phi^T\phi)$

If VEVs are such that: $\langle s\rangle \gg \langle\phi\rangle$

ACHTUNG!

∃ fine-tuning problem in the potential!

~Two possible solutions:

👎 Unnaturally set the coupling to zero: $\lambda_{s\phi}=0$

👍 Lower the scale: $\langle s\rangle \simeq \langle\phi\rangle$

Parametrization of s:

$s=(v_r+r)/\sqrt{2}\, e^{ia/f_a}$

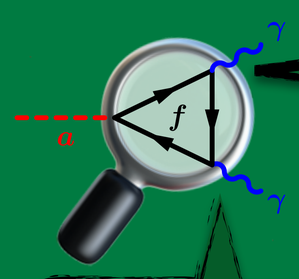
with a a QCD axion/ALP

and

$f_a \equiv \langle r\rangle \equiv v_r$

2. Axions or Axion-Like Particles (ALPs)?

f_a bounds from experimental limits on the $a\gamma\gamma$ coupling:



If a = QCD axion with $m_a < 10$ eV

$f_a \gtrsim |g_{a\gamma\gamma}| \times 10^7$ GeV

FINE-TUNING !!!

Even worse for 10 eV $< m_a <$ 0.1 GeV

Bounds much more relaxed for a = ALP of $m_a > 0.1$ GeV!!!

GOAL → Avoid the fine-tuning considering an ALP in the MLσM and imposing $f_a \simeq f$

3. Minimal Linear σ Model (MLσM)

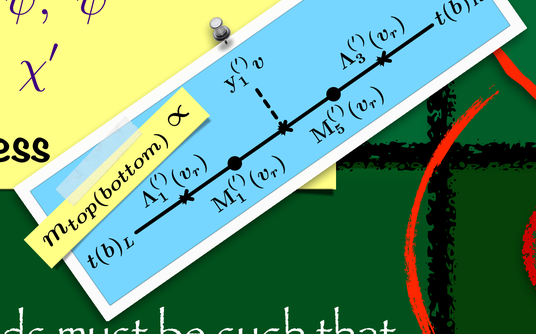
~ Renormalizable description that falls into a Minimal Composite Higgs Model (MCHM) in a specific limit

INGREDIENTS

1. **Spontaneously Broken Global Symmetry:**

$SO(5)\times U(1)_X \xrightarrow{f\,\approx\,\text{TeV}} SO(4)\times U(1)_X$

2. **Spectrum**
   - **The SM gauge bosons**
   - **The 3rd family of SM quarks**
   - **A $SO(5)$ real scalar quintuplet:** $\phi \sim \begin{pmatrix} H \\ \tilde{H} \\ \sigma \end{pmatrix}$ (SM Higgs doublet; Heavy EW singlet)
   - **Four exotic fermions**
     - **+Two $SO(5)$ quintuplets:** $\psi,\ \psi'$
     - **+Two $SO(5)$ singlets:** $\chi,\ \chi'$
3. **Fermion partial compositeness**



4. Axions/ALPs in the MLσM (AMLσM)

– Add the Peccei-Quinn symmetry: $SO(5)\times U(1)_X \times U(1)_{PQ}$

– Extend the spectrum by adding S

Coleman-Weinberg Mechanism

~It allows to extract the 1-loop divergences

~For renormalizability and a viable EWSB, the divergent terms that cannot be reabsorbed in $V^{\text{tree-level}}_{(s,\phi)}$ must be added

5. Requirements

The PQ charge assignments of the fields must be such that each resulting realization is:

1. MINIMAL: it has the smallest number of parameters

Independently of the PQ charges, two 1-loop divergent terms come from the gauge sector, thus:

MINIMAL ≈ No CW contributions from the fermonic sector

2. REALISTIC: A fermionic seesaw provides the SM top and bottom masses

3. NATURAL: ∄ large hierarchy between f and f_a, while describing m_{top} at the order of the EW scale

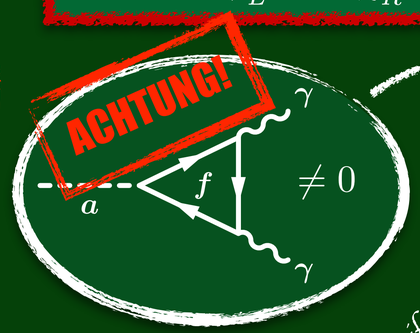
6. Example

n_i = PQ charge of the field "i"

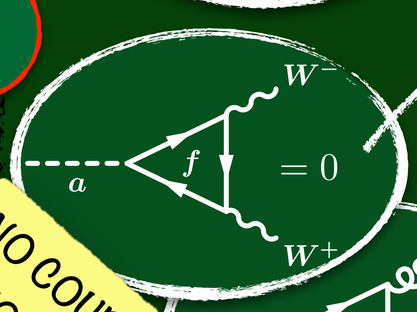
M_1^-

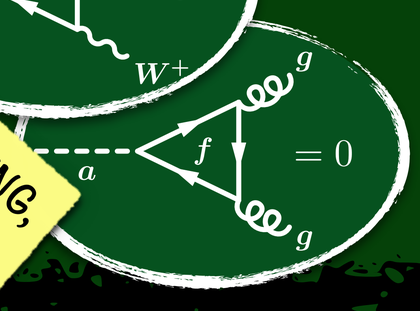
$n_{\psi_L} = n_{\chi_R} = n_{\psi_R} = n_{\chi_L} - n_s = n_{q_L} = n_{t_R} - 2n_s$

$= n_{\psi'_L} = n_{\chi'_R} = n_{\psi'_R} = n_{\chi'_L} + n_s = n_{b_R} + 2n_s$



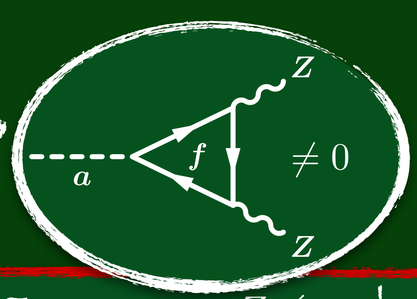
ALP with $m_a > 0.1$ GeV





NO COUPLING, NO BOUND

if $g_{aWW}=0$, g_{aZZ} gives the most relevant bound



From mono-Z signals, for $m_a \leq 1$GeV, we obtain:

$f_a \gtrsim 2.3$ TeV

MISSION ACCOMPLISHED

$f_a \simeq f \approx$ TeV