The $\gamma\gamma \rightarrow \phi\phi$ processes in the type-III 2HDM.

by C. H. Honorato

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by J. Hernandez-Sanchez, C. G. Honorato, M. A. Perez and J. J. Toscano.
The Model

The most general potential for this model is:

\[ V(\Phi_1, \Phi_2) = \mu_1^2(\Phi_1^\dagger \Phi_1) + \mu_2^2(\Phi_2^\dagger \Phi_2) - [\mu_{12}^2(\Phi_1^\dagger \Phi_2) + H.c. + \frac{1}{2} \lambda_1(\Phi_1^\dagger \Phi_1)^2
\]
\[ + \frac{1}{2} \lambda_2(\Phi_2^\dagger \Phi_2)^2 + \lambda_3(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + \lambda_4(\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1)
\]
\[ + \left[ \frac{1}{2} \lambda_5(\Phi_1^\dagger \Phi_2)^2 + [\lambda_6(\Phi_1^\dagger \Phi_1) + \lambda_7(\Phi_2^\dagger \Phi_2)](\Phi_1^\dagger \Phi_2) + H.c. \right], \]

There are three popular types, these are:

<table>
<thead>
<tr>
<th>Type</th>
<th>Parameters</th>
<th>Yukawa sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>( M_h, H, A, H^\pm, \alpha, \beta, \mu_{12} )</td>
<td>Only one doublet (like SM)</td>
</tr>
<tr>
<td>II</td>
<td>( M_h, H, A, H^\pm, \alpha, \beta, \mu_{12} )</td>
<td>One for up quarks, other for down</td>
</tr>
<tr>
<td>III</td>
<td>( M_h, H, A, H^\pm, \alpha, \beta, \mu_{12}, \lambda_6, \lambda_7, \chi_{qq} )</td>
<td>both (FCNC)</td>
</tr>
</tbody>
</table>

then, the main characteristics of these models are:
The Gauge-Fixing Procedure

We introduce a nonlinear gauge covariant under the electromagnetic gauge group and consistent with renormalization theory.

The main impact to the $\gamma\gamma \rightarrow \phi_i\phi_j$ processes are:

- The couplings $WG_W\gamma$ and $\phi_aWG_W\gamma$ are removed,
- The unphysical vertices $\phi_aWG_W$ are modified.

As an example, the following diagrams not appear

\[\begin{align*}
\text{on another hand, this kind of diagrams show gauge invariance itself}
\end{align*}\]
The Feynman diagrams and the impact of 2HDM-III

The processes are defined by next set of Feynman diagrams

Here, the blue point show the Yukawa vertices, and the red points are related with auto-Higgs couplings.
Discussion

The decoupling limit

\[ h \rightarrow h_{SM}, \ m_A \sim m_{H^\pm} \sim m_H \gg v, \ \alpha = \beta - \pi/2, \]

there are two options

a) \( \mu_{12} \gg v \) and \( \tan \beta \sim 1 \),  
b) \( \mu_{12} \sim v \), \( \tan \beta \gg 1 \) and \( \lambda_6, \lambda_7 \neq 0 \).
SM-Like

\( h \rightarrow h_{SM}, \ m_A \sim m_{H^\pm} \sim m_H \sim \mu_{12} \sim v, \ \alpha = \beta - \pi/2, \)

In particular way

\( m_h = 120 \text{ GeV}, \ m_A = 110 \text{ GeV}, \ m_H = m_{H^\pm} = m_A \)
**General 2HDM-III**

For this scenario, we take the following masses:

\[ m_{H^\pm} = 400 \text{ GeV} , \quad m_A = 350 \text{ GeV} , \quad m_H = 520 \text{ GeV} , \quad m_h = 120 \text{ GeV} , \quad \mu_{12} = 120 \text{ GeV} , \quad \tan \beta = 5 \]

and different values for \( \alpha, \lambda_{6,7} \) and \( \chi_{uu,dd} \).
Conclusions

- We present the study of one-loop $\gamma\gamma \rightarrow \phi_i\phi_j$ processes in the context of a general two doublet model.

- A nonlinear $R_\xi$ -- gauge was implemented, this reduced the number of Feynman diagrams.

- We could see the decoupling limit for 2HDM-III, via $\tan\beta \gg 1$.

- The parameter related with the 2HDM-III ($\lambda_{6,7}$ and $\chi_{uu,dd}$) make grow up the cross section around one or two orders.