CP violation through particle mixing and the $H-A$ lineshape

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Based on:
J. Bernabéu, D. Binosi, and J. P.
The H-A system

In the two-Higgs doublet models in general and in most SUSY scenarios in particular the extended scalar sector contains the typical system of the scalars, the CP-even $H$ and the CP-odd $A$

At tree-level

$$m^2_H = \frac{1}{2} \left[ M_Z^2 + m_A^2 + \sqrt{(M_Z^2 + m_A^2)^2 - 4m_A^2 M_Z^2 \cos^2 2\beta} \right]$$

In the decoupling limit $M_A \gg M_Z$,

$$m^2_H \approx m_A^2 + M_Z^2 \sin^2 2\beta,$$

which, for $\tan \beta \geq 2$ (and thus $\cos^2 2\beta \approx 1$), implies the near degeneracy $m_H \approx m_A$. 

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The inclusion of radiative corrections does not lift the mass degeneracy in the $H$-$A$ system, especially if $m_A > 2M_Z$ and $\tan \beta \geq 2$.


$\implies$ s-channel production would lead to nearly overlapping resonances
If CP exact \( \implies \) \( H \) does not mix with \( A \) 

But: CP-violating effects may connect them, giving origin to one-loop particle mixing.

![Diagram of particle mixing](image)

**\( H - A \) mixing due to:**

- Three generations of heavy Majorana neutrinos


Such CP-violating effects are resonantly enhanced, due to the mass degeneracy of the \( H - A \) system A. Pilaftsis, Nucl. Phys. B 504, 61 (1997).

Effects on lineshape of the $H - A$ system

Example: $\mu^+\mu^- \rightarrow A^*, H^* \rightarrow b\bar{b}$

For a given separation between the resonances we have two physically very different possibilities

- CP exact $\iff \sin^2 2\beta = (m_H^2 - m_A^2)/M_Z^2$
- $\sin^2 2\beta \ll (m_H^2 - m_A^2)/M_Z^2$, but the two resonances are further apart due to CP violation effects

**Question**

Can the effects due to CP-violating mixing be mimicked by (or be re-absorbed into) a simple redefinition of the $H$ and $A$ masses in the context of a CP-conserving model?
Answer: In general, no

Either: (i) the mass-splitting of the $H$ and $A$ bosons cannot be accounted for in the absence of CP-mixing, or (ii) the detailed energy dependence of the produced lineshape is clearly different from the one obtained by redefining the masses, but not allowing any mixing.
The detailed study of the lineshape of the $H$-$A$ system may provide valuable information on the CP nature of the underlying theory.