CP violation through particle mixing and the H-A lineshape

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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

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

In the decoupling limit $M_A \gg M_Z$,

$$m_H^2 \approx m_A^2 + M_Z^2 \sin^2 2\beta,$$

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

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

G.L. Kane, C. Kolda, L. Roszkowksi and J.D. Wells, Phys. Rev. **D49**, 6173 (1994)

$\implies$ *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 .
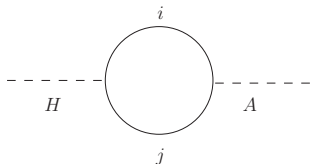
$H - A$ mixing due to:

- Large CP-violating Yukawa couplings to the top and bottom squarks. A. Pilaftsis, Phys. Lett. B **435**, 88 (1998).

- Three generations of heavy Majorana neutrinos

J. Bernabeu, J. G. Korner, A. Pilaftsis and K. Schilcher, Phys. Rev. Lett. **71**, 2695 (1993); A. Ilakovac, B. A. Kniehl and A. Pilaftsis, Phys. Lett. B **317**, 609 (1993). Such CP-violating effects are resonantly enhanced, due to the mass degeneracy of the the $H-A$ system A. Pilaftsis, Nucl. Phys. B **504**, 61 (1997).
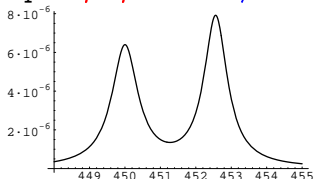
CP-violating effects lift the original mass degeneracy between H and A. M. Carena, J. R. Ellis, A. Pilaftsis and C. E. Wagner, Nucl. Phys. B **625**, 345 (2002).

Complete study with radiative corrections included [code CPsuperH]. J. Bernabéu, D. Binosi, and J. Papavassiliou, JHEP 0609:023,2006.
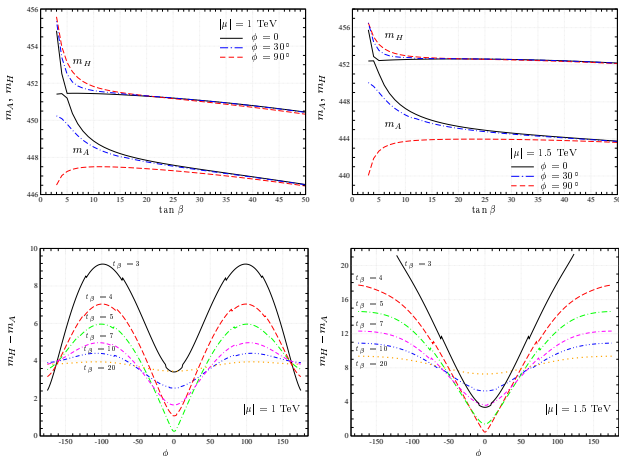
Effects on lineshape of the $H - A$ system

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

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

- CP exact $\implies \sin^2 2\beta = (m_H^2 - m_A^2)/M_Z^2$
- $\sin^2 2\beta \ll (m_H^2 - m_A^2)/M_Z^2$, 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 ?
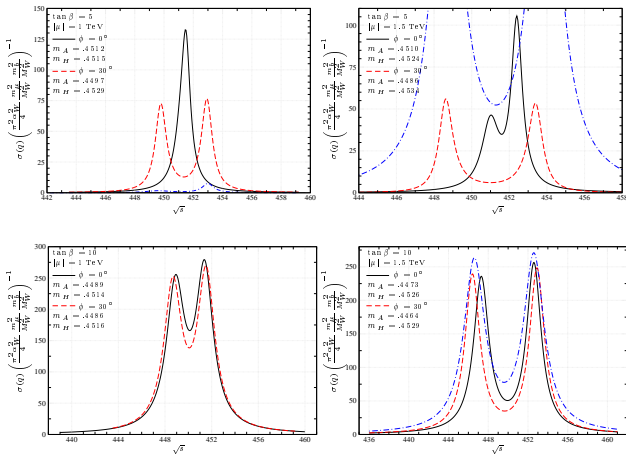
Answer: In general, no

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.