



Light Charged and CP-odd Higgses *in MSSM-like models at $\tan \beta \simeq 1$*

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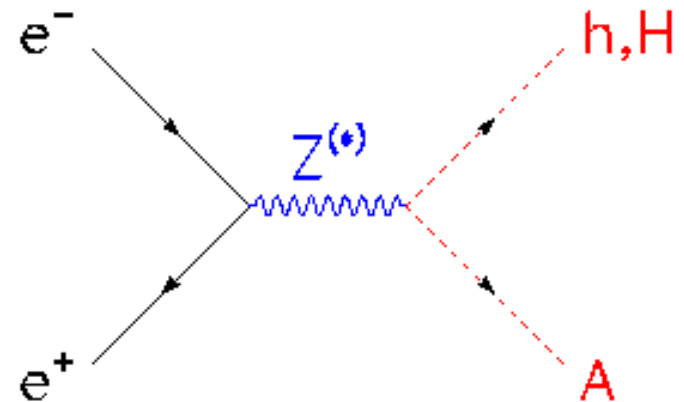
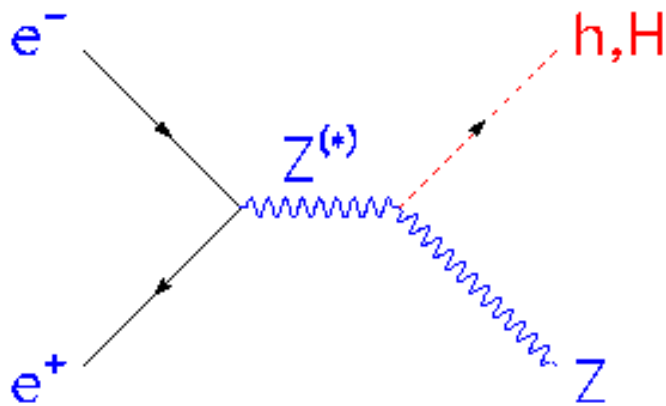
R.D. [arXiv:0806.0847](https://arxiv.org/abs/0806.0847), [arXiv:0806.tomorrow](https://arxiv.org/abs/0806.tomorrow)

Higgs sector in the MSSM

$$M^2 \simeq \begin{pmatrix} m_A^2 s_\beta^2 + m_Z^2 c_\beta^2 & -(m_A^2 + m_Z^2) s_\beta c_\beta \\ -(m_A^2 + m_Z^2) s_\beta c_\beta & m_Z^2 s_\beta^2 + m_A^2 c_\beta^2 + \Delta \end{pmatrix}, \quad r_\Delta = \frac{\Delta}{m_Z^2}$$

diagonalized by $R(\alpha)$, and results in ZZh coupling: $C_{ZZh} = \frac{g_{ZZh}^2}{g_{ZZh,SM}^2} = \sin^2(\beta - \alpha)$

$$C_{ZZH} = \cos^2(\beta - \alpha), \quad C_{ZA h} = \cos^2(\beta - \alpha), \quad C_{ZA H} = \sin^2(\beta - \alpha)$$



Higgs sector in the MSSM

□ $m_A \ll m_Z$ for $\Delta \simeq 0$:

$$m_h^2 \simeq m_A^2 \cos^2 2\beta$$

$$m_H^2 \simeq m_Z^2$$

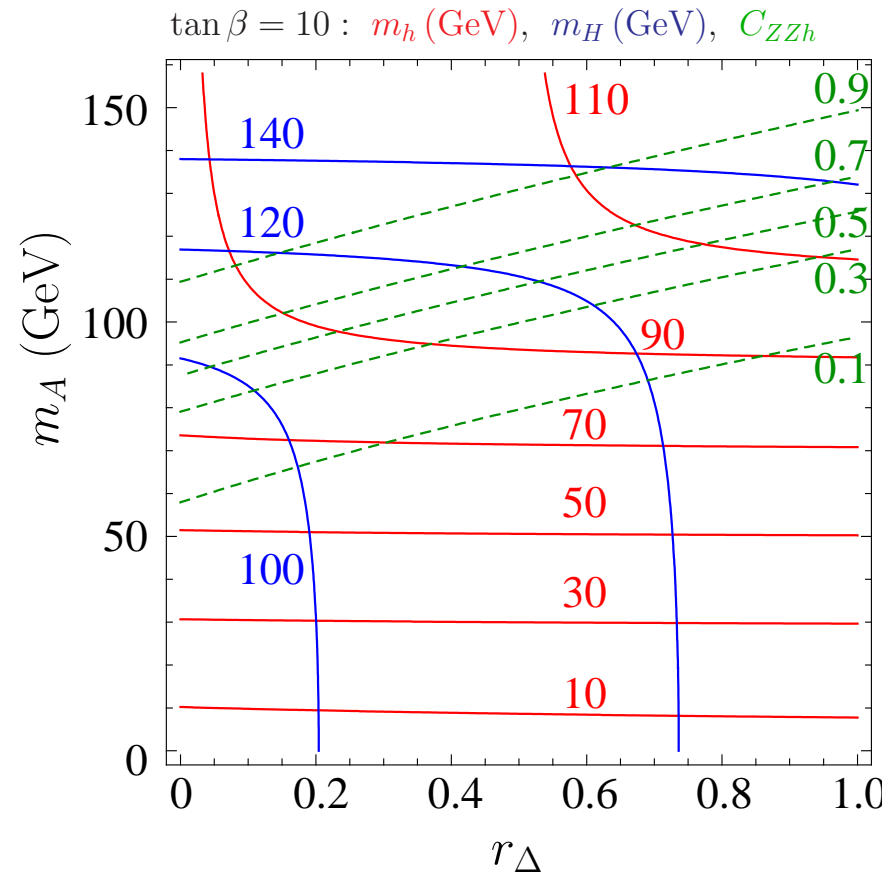
$$C_{ZZH} \simeq \cos^2 2\beta$$

$m_A \gg m_Z$:

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \Delta \sin^2 \beta$$

$$m_H^2 \simeq m_A^2$$

$$C_{ZZh} \simeq 1$$



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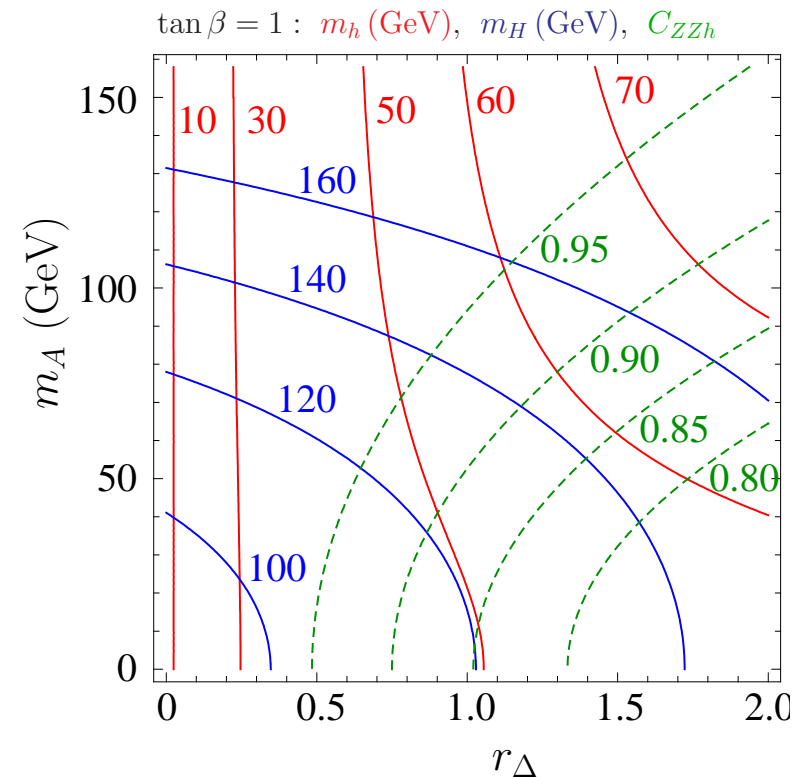
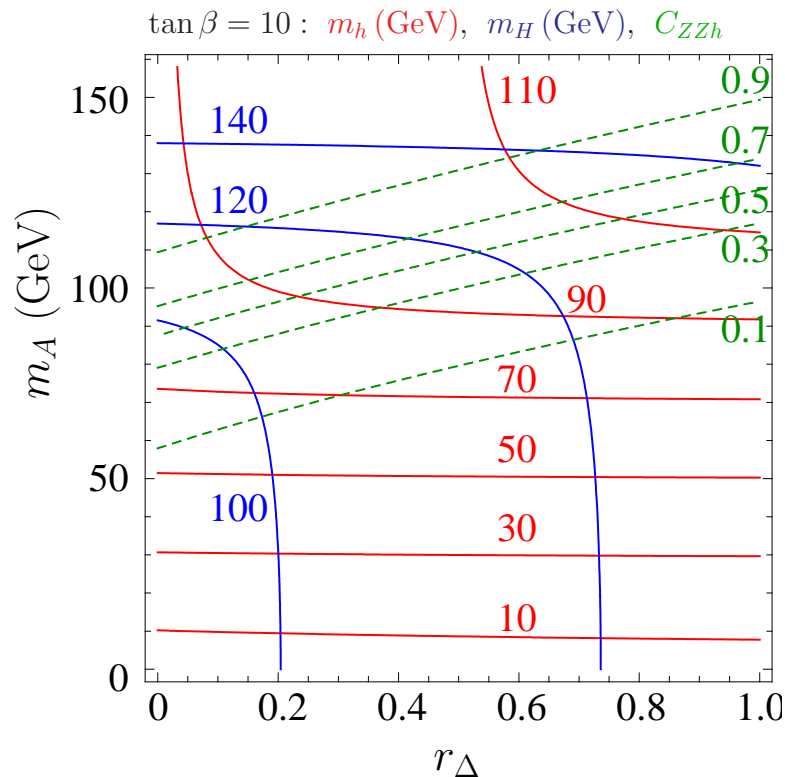
$$C_{ZZH} \simeq \cos^2 2\beta$$

$m_A \ll m_Z$ at $\tan \beta \simeq 1$:

$$m_h^2 \simeq \Delta/2$$

$$m_H^2 \simeq m_Z^2 + m_A^2 + \Delta/2$$

$$C_{ZZH} \simeq 0, \quad C_{ZZh} \simeq 1$$



MSSM at $m_A \ll m_Z$ and $\tan \beta \simeq 1$

$$m_h^2 \simeq \Delta/2$$

$$m_h \simeq 38 - 56 \text{ GeV}$$

$$m_H^2 \simeq m_Z^2 + m_A^2 + \Delta/2$$

$$m_H \simeq 108 - 150 \text{ GeV}$$

$$C_{ZZh} \simeq 1$$

$$C_{ZZh} \simeq 0.84 - 0.97$$

$$m_{H^\pm} = \sqrt{m_W^2 + m_A^2 - \Delta'} \simeq m_W^2$$

$$m_{H^\pm} \simeq 78 - 80 \text{ GeV}$$

FeynHiggs2.6.3, with $m_t = 172.6 \text{ GeV}$

($m_A = 8 \text{ GeV}$, $\tan \beta = 1.01$, $\mu = 100 \text{ GeV}$, $M_{SUSY} < 1 \text{ TeV}$, $-2 < X_t/m_{\tilde{t}} < 0$)

$$B(h \rightarrow AA, b\bar{b}) \simeq 90\%, 10\%$$

$$B(A \rightarrow \tau^+\tau^-, c\bar{c}, gg) \simeq 50\%, 40\%, 10\%$$

fixed by $\tan \beta$ for $2m_\tau \lesssim m_A \lesssim 10 \text{ GeV}$

$$B(H \rightarrow ZA, AA, hh, b\bar{b}) \simeq 37\%, 34\%, 28\%, 0.4\%$$

for 1 TeV SUSY and $X_t/m_{\tilde{t}} = 0$

$$B(H^+ \rightarrow W^{+*}A, \tau^+\nu, c\bar{s}) \simeq 70\%, 20\%, 10\%$$

$$B(t \rightarrow H^+b) \simeq 40\%, \quad B(t \rightarrow W^+b) \simeq 60\%$$

Light CP even Higgs

h could have been produced at LEP in $e^+e^- \rightarrow Zh$ with
 $B(h \rightarrow 2\tau 2c, 4\tau, 4c, b\bar{b}, \dots) \simeq 36\%, 23\%, 14\%, 10\%, \dots$

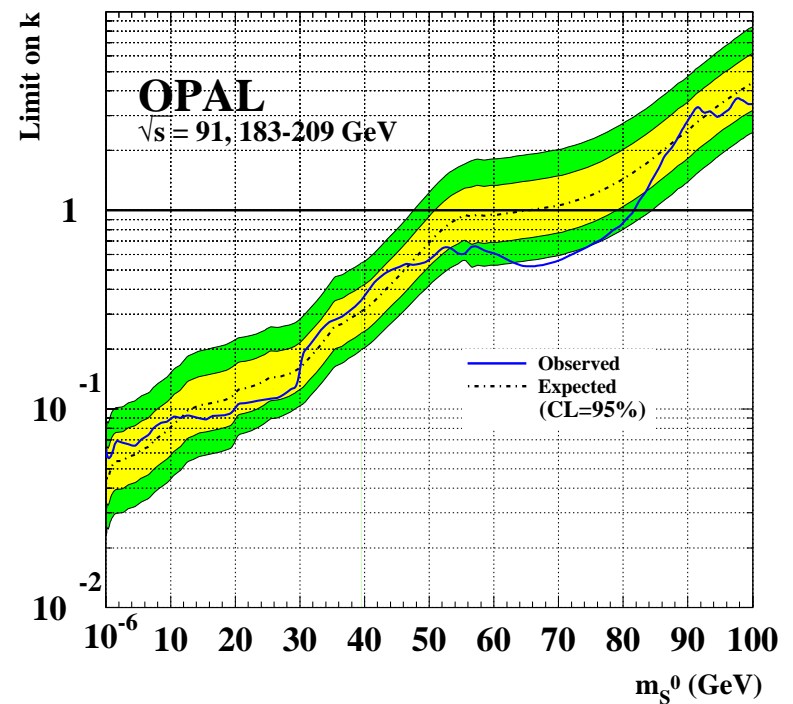
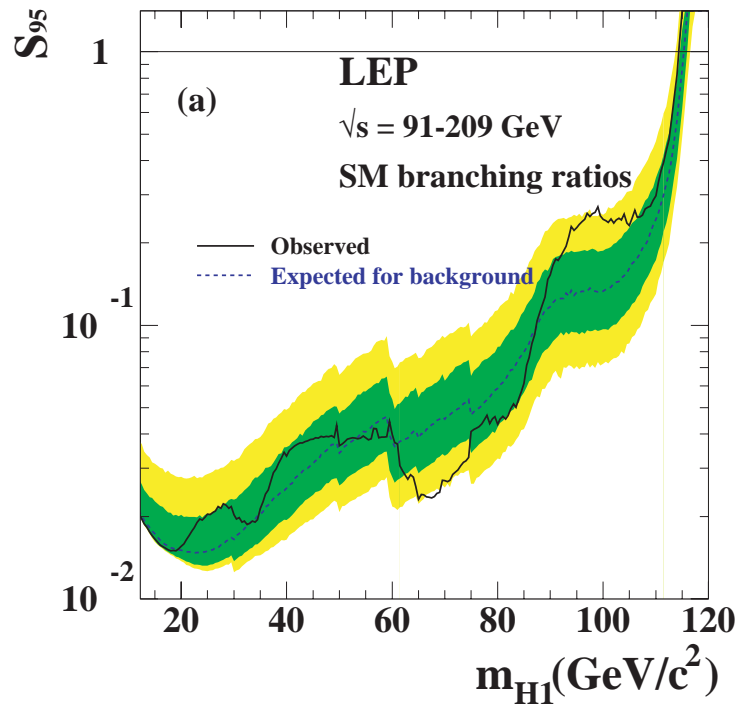
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Strongest limits from:

$h \rightarrow b\bar{b}$

decay-mode independent



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we need: $m_h \gtrsim 82 \text{ GeV}$

ruled out in MSSM!

can easily be viable in beyond MSSM, e.g. singlet extensions:

$$W \supset \lambda S H_u H_d$$

increases Higgs quartic coupling, and

$$m_h^2 \simeq \dots + \lambda^2 v^2 \sin^2 2\beta + \dots$$

$$v = 174 \text{ GeV}$$

Heavy CP even Higgs

H could have been produced at LEP in $e^+e^- \rightarrow HA$ with
 $B(H \rightarrow ZA, AA) \simeq 50\%, 50\%$ if $H \rightarrow hh$ not open
NO SEARCH for: $e^+e^- \rightarrow HA \rightarrow (ZA)A$

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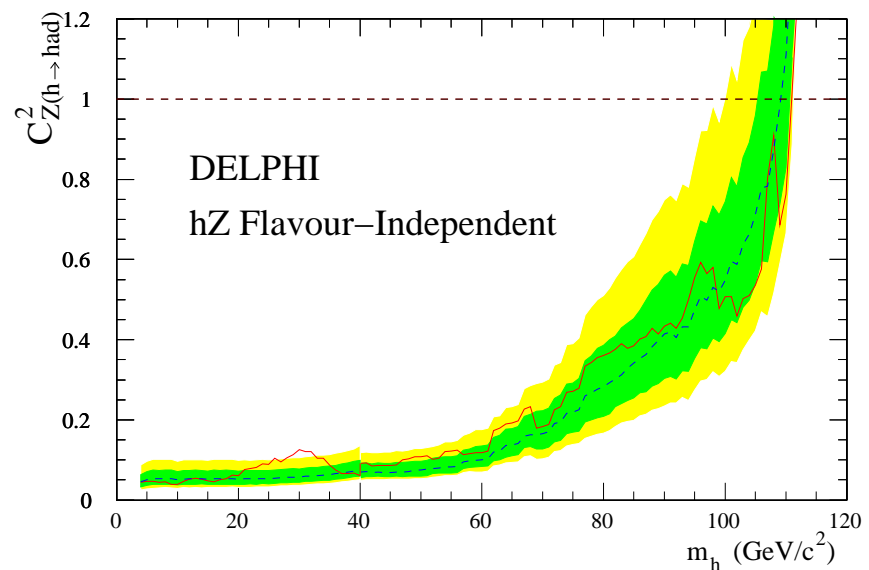
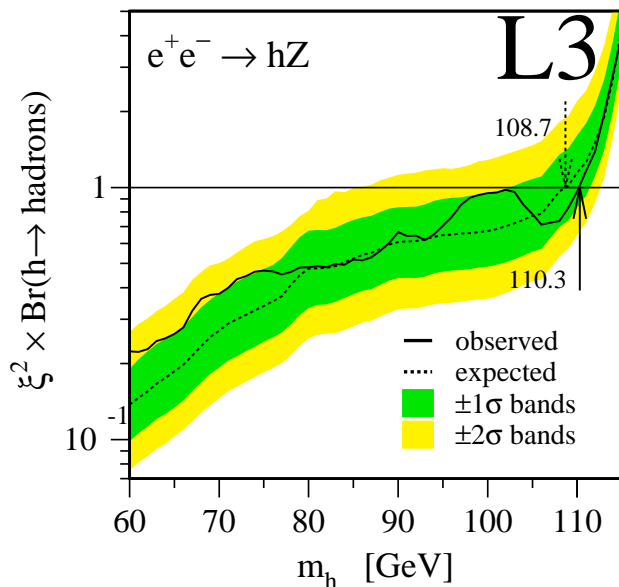
NO SEARCH for: $e^+e^- \rightarrow HA \rightarrow (ZA)A$

however, it would contribute to:

$e^+e^- \rightarrow Zh \rightarrow Z(AA)$ or $e^+e^- \rightarrow Zh \rightarrow Z + jets$

with wrong reconstructed Higgs mass!

e.g. in flavor independent searches:



Heavy CP even Higgs

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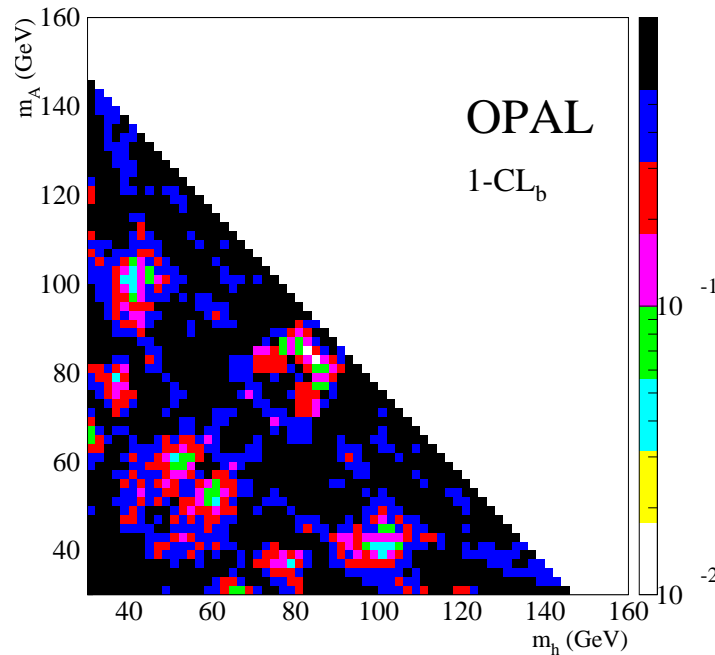
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however, it would contribute to:

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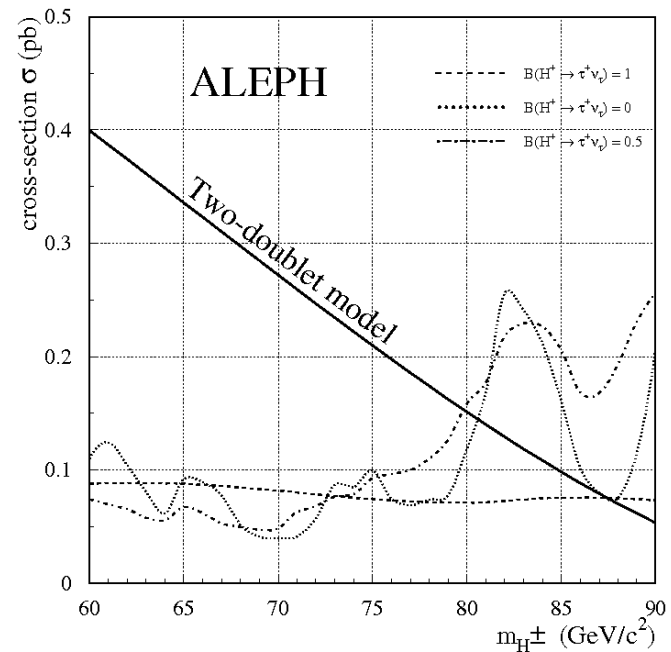
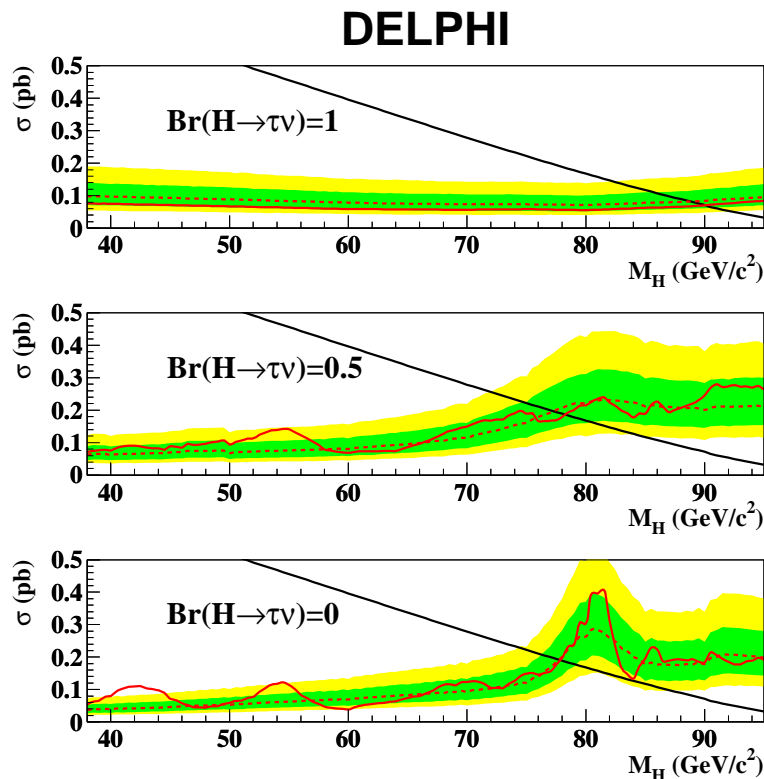
Charged Higgs

H^\pm could have been produced at LEP: $e^+e^- \rightarrow H^+H^-$ with $B(H^+ \rightarrow W^{+\ast}A, \tau^+\nu, c\bar{s}) \simeq 70\%, 20\%, 10\%$

NO SEARCH for: $H^\pm \rightarrow W^{\pm\ast}A$ with $A \rightarrow \tau^+\tau^-, c\bar{c}, gg$

Strongest limits from ALEPH: $m_{H^\pm} > 79.3$ GeV

assuming $B(H^+ \rightarrow \tau^+\nu) + B(H^+ \rightarrow c\bar{s}) = 1$



Charged Higgs

H^\pm could have been produced at Tevatron: $t \rightarrow H^+ b$ with

$B(t \rightarrow H^+ b) \simeq 40\%$, $B(H^+ \rightarrow W^{+\ast} A, \tau^+ \nu, c\bar{s}) \simeq 70\%, 20\%, 10\%$

NO SEARCH for: $H^\pm \rightarrow W^{\pm\ast} A$ with $A \rightarrow \tau^+ \tau^-, c\bar{c}, gg$

Strongest limits from CDF:

from 193 pb^{-1} of data!!!

□ $B(t \rightarrow H^+ b) < 0.4$

assuming $B(H^+ \rightarrow \tau^+ \nu) = 1$

□ $B(t \rightarrow H^+ b) < 0.8$ for $m_{H^\pm} \simeq 80 \text{ GeV}$

assuming $H^+ \rightarrow \tau^+ \nu, c\bar{s}, t\bar{b}$ or $W^+ A$ with $A \rightarrow b\bar{b}$

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No limits for $m_{H^\pm} \gtrsim 75 \text{ GeV}$ from LEP or Tevatron!

Light CP-odd Higgs at B factories

A could have been produced at B-factories: $\Upsilon \rightarrow A\gamma$

(it is advantageous to search in $\Upsilon(1S)$, $(2S)$ and $(3S)$ data)

results obtained from

R.D., J. F. Gunion and B. McElrath, hep-ph/0612031

taking $\tan\beta \cos\theta_A \simeq 1$:

$$B(\Upsilon(1S) \rightarrow A\gamma) \simeq 5 \times 10^{-5}$$

for $m_A \simeq 2m_\tau$

$$B(\Upsilon(1S) \rightarrow A\gamma) \simeq 10^{-7}$$

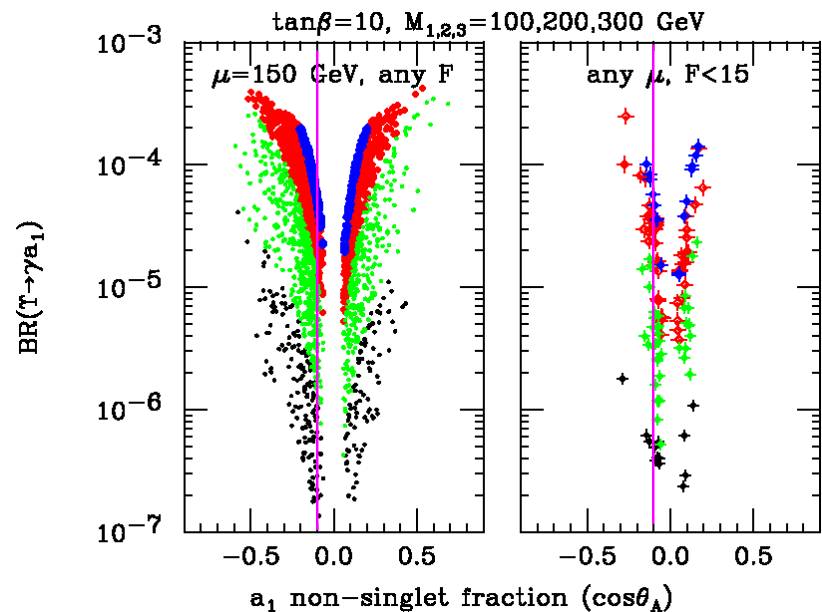
for $m_A \simeq 9.2 \text{ GeV}$

CLEO preliminary limits:

assuming $B(A \rightarrow \tau^+\tau^-) = 1$

$$B(\Upsilon(1S) \rightarrow A\gamma) < 7 \times 10^{-5} - 8 \times 10^{-6}$$

depending on exact m_A



$$m_{a_1} < 2m_\tau$$

$$2m_\tau < m_{a_1} < 7.5 \text{ GeV}$$

$$7.5 \text{ GeV} < m_{a_1} < 8.8 \text{ GeV}$$

$$8.8 \text{ GeV} < m_{a_1} < 9.2 \text{ GeV}$$

Lepton universality in W boson decays

□ measured at LEP in $e^+e^- \rightarrow W^+W^-$

arXiv:hep-ex/0412015

$$B(W \rightarrow \mu\nu)/B(W \rightarrow e\nu) = 0.994 \pm 0.020$$

$$B(W \rightarrow \tau\nu)/B(W \rightarrow e\nu) = 1.070 \pm 0.029$$

$$B(W \rightarrow \tau\nu)/B(W \rightarrow \mu\nu) = 1.076 \pm 0.028$$

$$R_{\tau/l} \equiv 2B(W \rightarrow \tau\nu)/(B(W \rightarrow e\nu) + B(W \rightarrow \mu\nu))$$

2.8 σ deviation from lepton universality:

$$R_{\tau/l}^{exp} = 1.073 \pm 0.026$$

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CDF, Nucl. Phys. Proc. Suppl. **144**, 323 (2005)

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H^\pm NOT expected to contribute!

Charged Higgs contribution to $R_{\tau/l}$

- H^\pm contribution to $\tau\nu\tau\nu$:

$$R_{\tau/l}^l = \sqrt{1 + \frac{\sigma_{H^+H^-} B(H^+ \rightarrow \tau^+\nu)^2}{\sigma_{W^+W^-} B(W^+ \rightarrow l^+\nu)^2}}$$

efficiency of $W \rightarrow \tau\nu$ event to pass as $W \rightarrow l\nu$ event is not negligible and so H^\pm effectively contributes also to mixed $\tau\nu l\nu$ channels

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- H^\pm contribution (simplified!) to $\tau\nu + \text{hadrons}$:

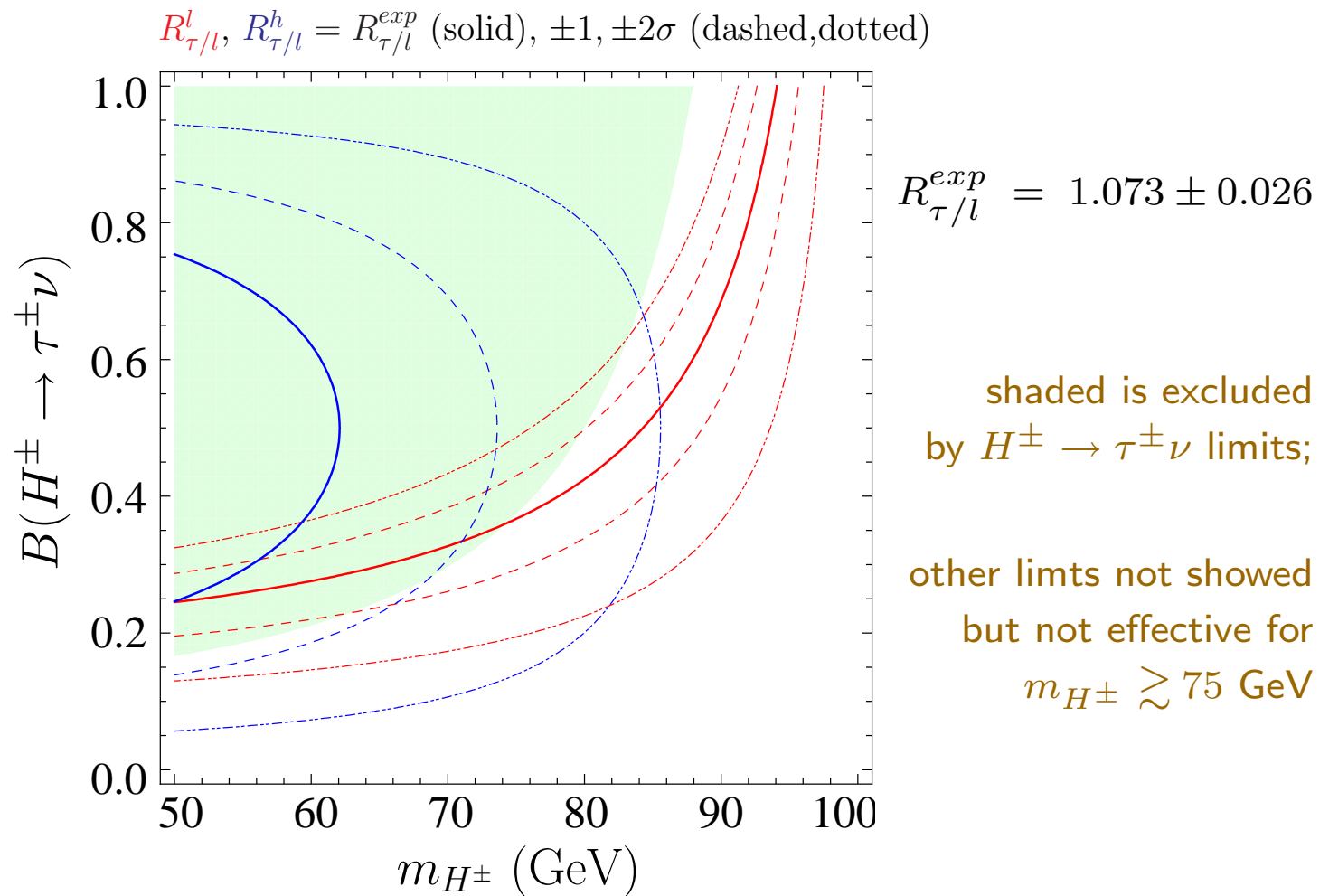
$$R_{\tau/l}^h = 1 + \frac{\sigma_{H^+H^-} B(H^+ \rightarrow \tau^+\nu) B(H^+ \rightarrow \text{hadrons})}{\sigma_{W^+W^-} B(W^+ \rightarrow l^+\nu) B(W^+ \rightarrow \text{hadrons})}$$

underestimates by not including $H^+H^- \rightarrow c\bar{s}W^{-*}A$, $\bar{c}sW^{+*}A$, $W^{+*}AW^{-*}A$ with one $A \rightarrow \tau^+\tau^-$ that could mimic $WW \rightarrow \tau\nu + \text{hadrons}$

$$B(H^+ \rightarrow \text{hadrons}) \simeq 1 - B(H^+ \rightarrow \tau^+\nu)$$

overestimates $B(H^+ \rightarrow \text{hadrons})$ by including $B(H^+ \rightarrow W^{+*}A)$ with $A \rightarrow \tau^+\tau^-$, $\tau \rightarrow \text{leptons}$ and $W^{+*} \rightarrow \text{leptons}$

Charged Higgs contribution to $R_{\tau/l}$



$m_{H^\pm} \simeq 75 - 85$ GeV with $B(H^+ \rightarrow \tau^+ \nu) \simeq 20 - 40\%$ seems to explain $R_{\tau/l}$

Conclusions

$m_A \ll m_Z$ at $\tan\beta \simeq 1$ scenario viable in extensions of the MSSM; presents an opportunity to discover Higgs bosons at LEP, Tevatron, CLEO, BaBar, Belle:

- SM like CP even Higgs, $m_h \gtrsim 82$ GeV
 - ▶ produced in $e^+e^- \rightarrow Zh$
 - effective search would require combining $h \rightarrow 4\tau, 2\tau 2c, 4c, 2b$ modes
- heavy CP even Higgs, $m_h \simeq 108 - 150$ GeV
 - ▶ produced in $e^+e^- \rightarrow HA$
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- CP odd Higgs, $m_A \lesssim 10$ GeV
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- charged Higgs, $m_{H^\pm} \simeq m_W$
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