MSSM light Higgs boson scenario and its test at hadron colliders

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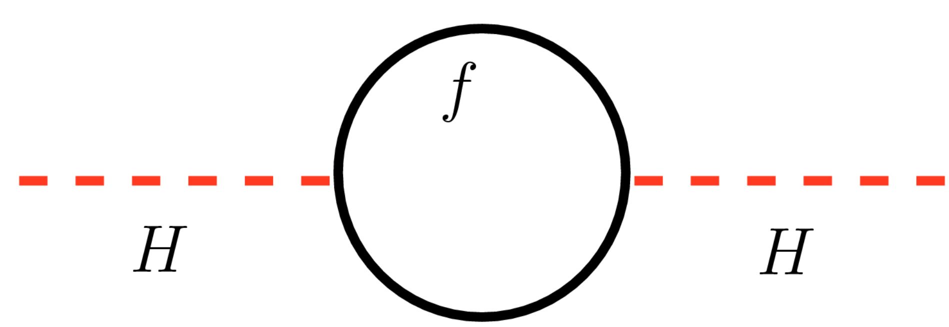
Summary

- The MSSM scenario with the CP-even Higgs boson as light as 60 GeV and above is not excluded by LEP2
- The MSSM parameter space corresponding to this Light higgs (Lh) scenario is generic and not fine-tuned
- The entire parameter space corresponding Lh scenario can be entirely covered by LHC

Problems of the Standard Model

- Problem of large quantum corrections to the Higgs mass in SM (Hierarchy problem)

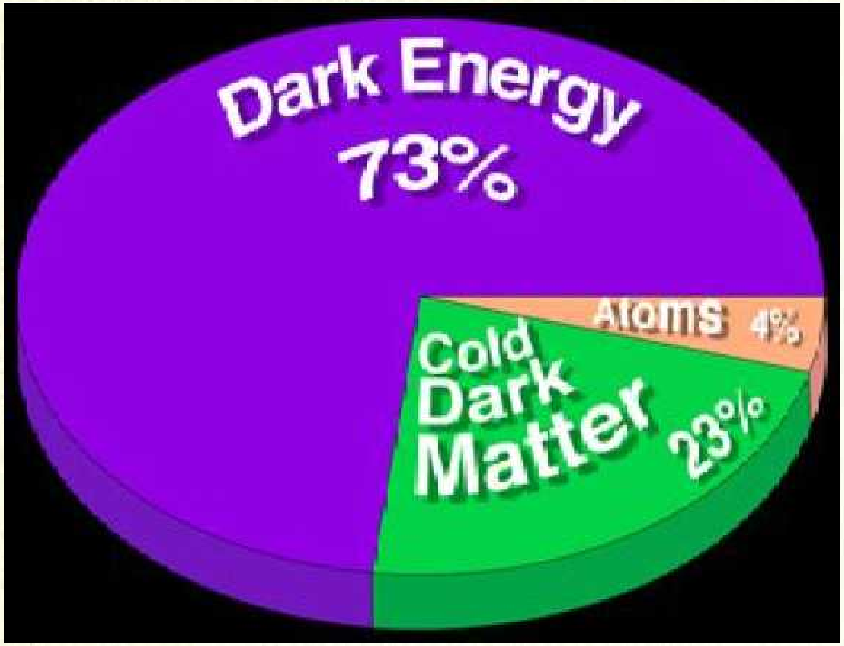


$$\delta m_H^2 = \frac{|\lambda_f|^2}{16\pi^2}[-2\Lambda_{UV}^2 + ...]$$

- Coupling Unification
- The origin of Electroweak Symmetry breaking.

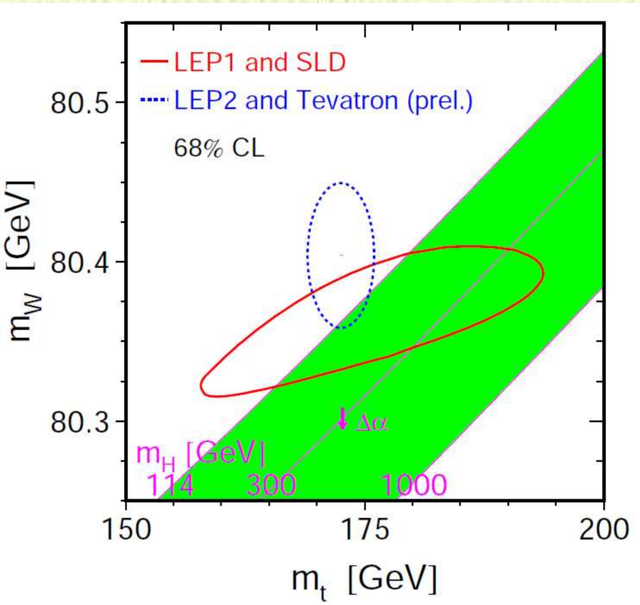
  Higgs boson is not found yet …
- The origin and Nature of Dark Matter and Dark Energy

  No explanation within SM …
- Baryogenesis problem



Constraints from Electroweak Data

LEP1+SLD+nN data are consistent with LEP2+Tevatron data and with SM, if Higgs mass is low

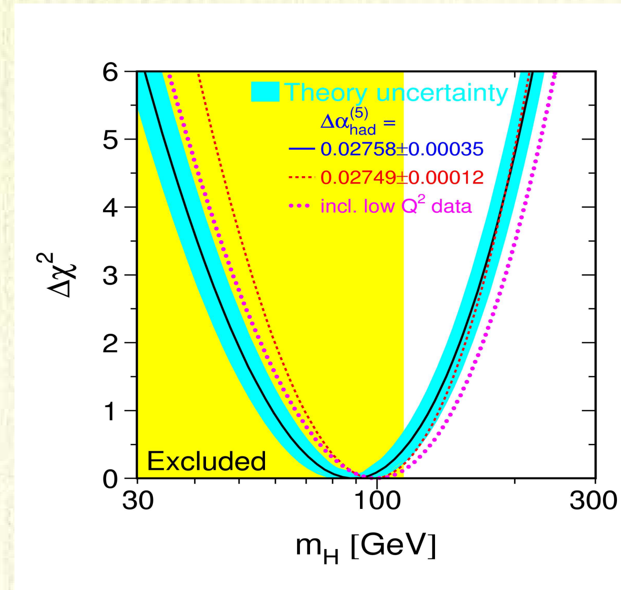


χ^2 versus M_H for SM Fit

- M_H=89 +42-30 @68%CL
- M_H < 175 GeV @95%CL

for m_{top}=172.5 GeV

by March 2006

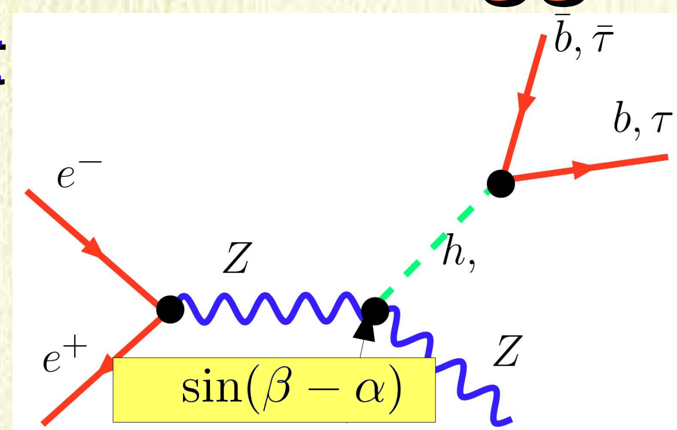


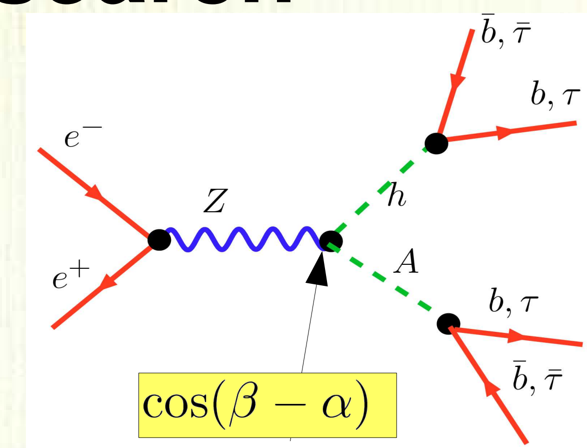
Current status of direct Higgs search

- LEP2 SM higgs limit

$$M_h > 114.4 \text{ GeV}$$

- There are more processes in SUSY





MSSM HIGGS sector

- To provide masses to both up-type and down-type quarks, and to ensure anomaly cancellation,the MSSM has two Higgs complex-doublet superfields

$$\Phi_d = (\Phi_d^0, \Phi_d^-) \text{ and } \Phi_u = (\Phi_u^+, \Phi_u^0) \qquad \langle\Phi_d\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} v_d \\ 0 \end{pmatrix}, \quad \langle\Phi_u\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ v_u \end{pmatrix},$$

where $\sqrt{v_d^2 + v_u^2} = 2M_W/g = 246 \text{ GeV}$

- Out of 8 DOF, 3 serve as GB, absorbed into longitudinal components of the W and Z, 5 DOF remains:

$$h = -(\sqrt{2}\text{Re } \Phi_d^0 - v_d)\sin\alpha + (\sqrt{2}\text{Re } \Phi_u^0 - v_u)\cos\alpha$$

$$H = (\sqrt{2}\text{Re } \Phi_d^0 - v_d)\cos\alpha + (\sqrt{2}\text{Re } \Phi_u^0 - v_u)\sin\alpha$$

$$A = \sqrt{2}(\text{Im } \Phi_d^0 \sin\beta + \text{Im } \Phi_u^0 \cos\beta), \quad H^\pm = \Phi_d^\pm \sin\beta + \Phi_u^\pm \cos\beta$$

α is (h, H) mixing angle

$\tan\beta = v_u/v_d$ and M_A is the conventional choice to define the Higgs sector:

$M_{H^\pm} = \sqrt{M_A^2 + M_W^2}$

$M_{h,H}^2 = \frac{1}{2}\left[(M_A^2 + M_Z^2) \mp \sqrt{(M_A^2 + M_Z^2)^2 - 4M_A^2 M_Z^2 \cos^2 2\beta}\right], \quad M_h < M_Z$

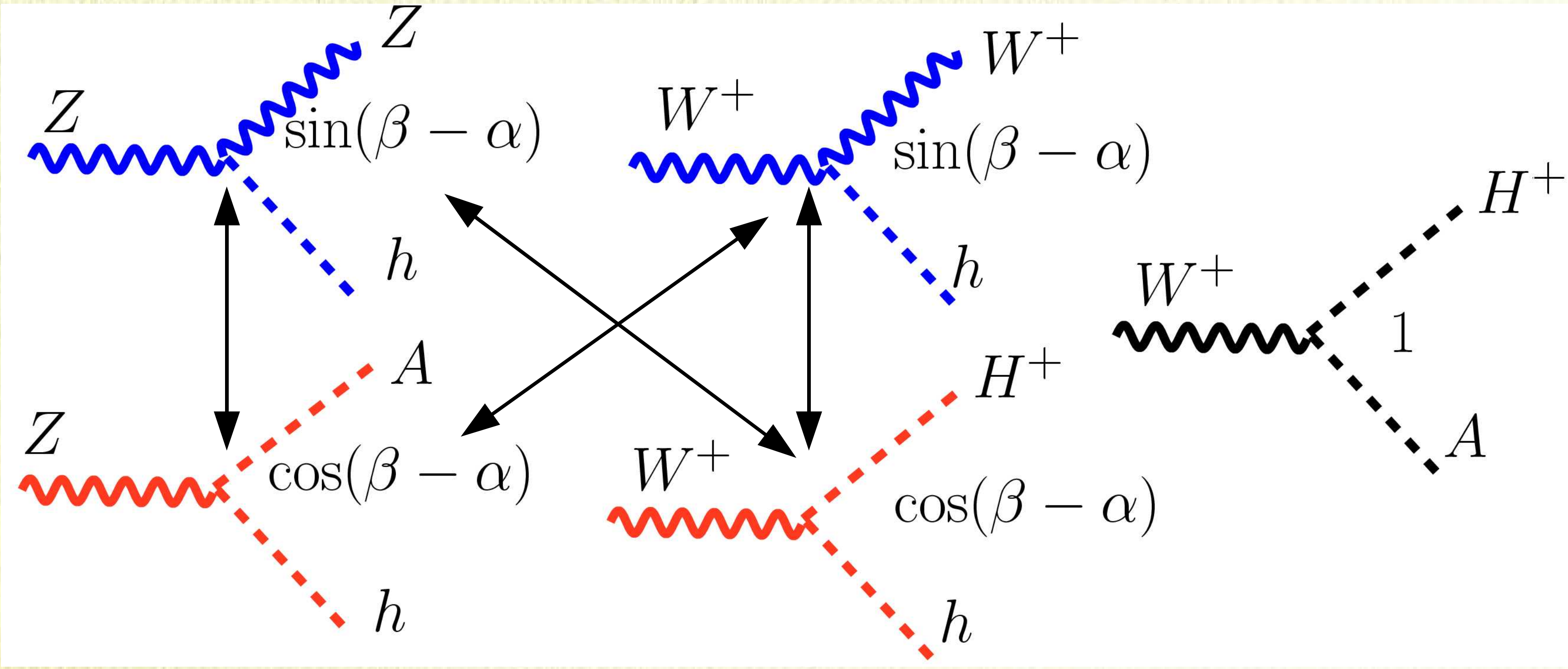
Higgs Interactions with vector bosons

$$\mathcal{L}_{H_iVV} = g\,M_W\,\left(W^+_\mu W^{-\mu} + \frac{1}{2c_W^2}\,Z_\mu Z^\mu\right)\,g_{H_iVV}\,H_i$$

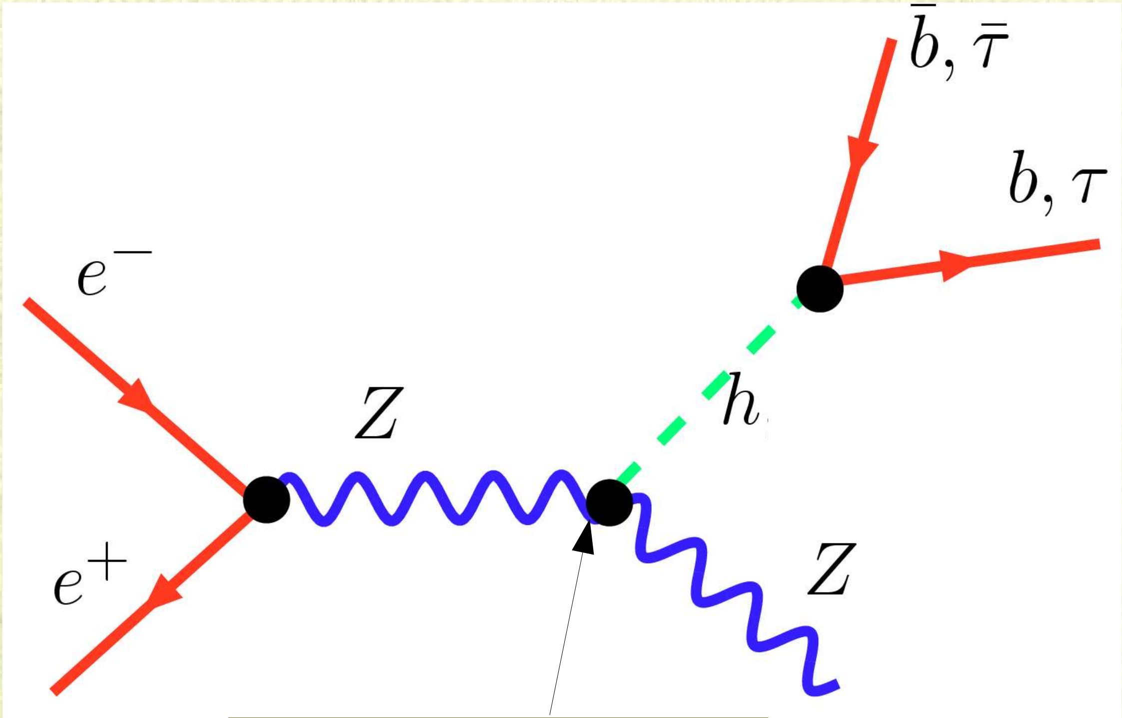
$$\mathcal{L}_{AH_iZ} = \frac{g}{4c_W} g_{AH_iZ}\,Z^\mu(H_i\,i\overleftrightarrow{\partial}_\mu\,A), \quad H_i = (h, H)$$

$$\mathcal{L}_{\mathcal{H}H^\pm W^\mp} = -\frac{g}{2}\,g_{\mathcal{H}H^+W^-}\,W^{-\mu}(\mathcal{H}\,i\overleftrightarrow{\partial}_\mu\,H^+) + \text{h.c.}, \quad \mathcal{H} = (h, H, A)$$

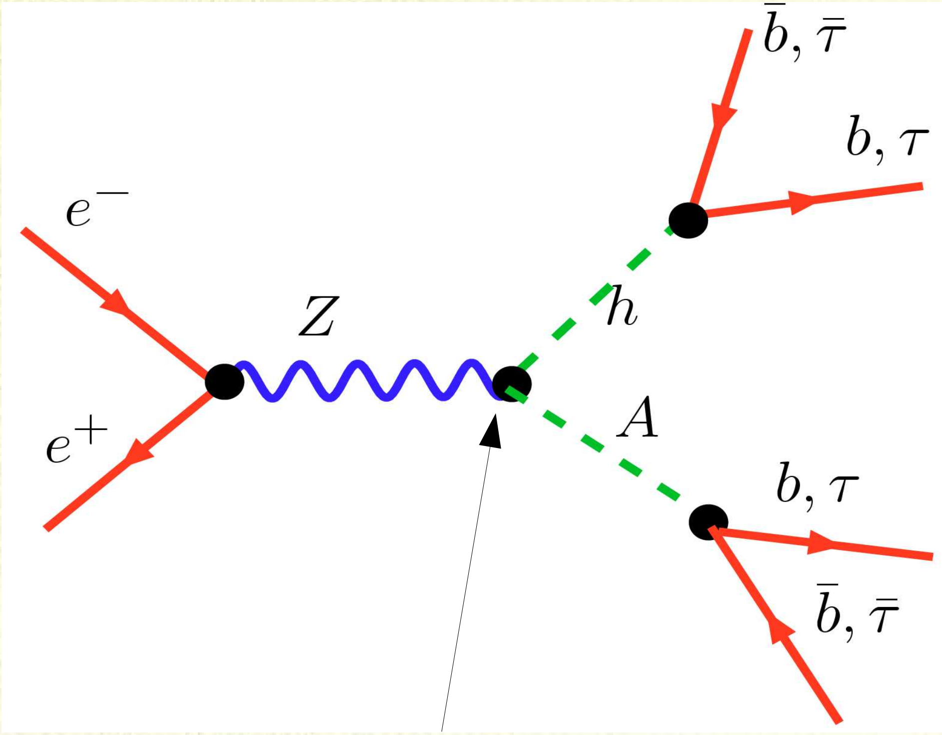
Sum rules



Will no-lose 'theorem' work?



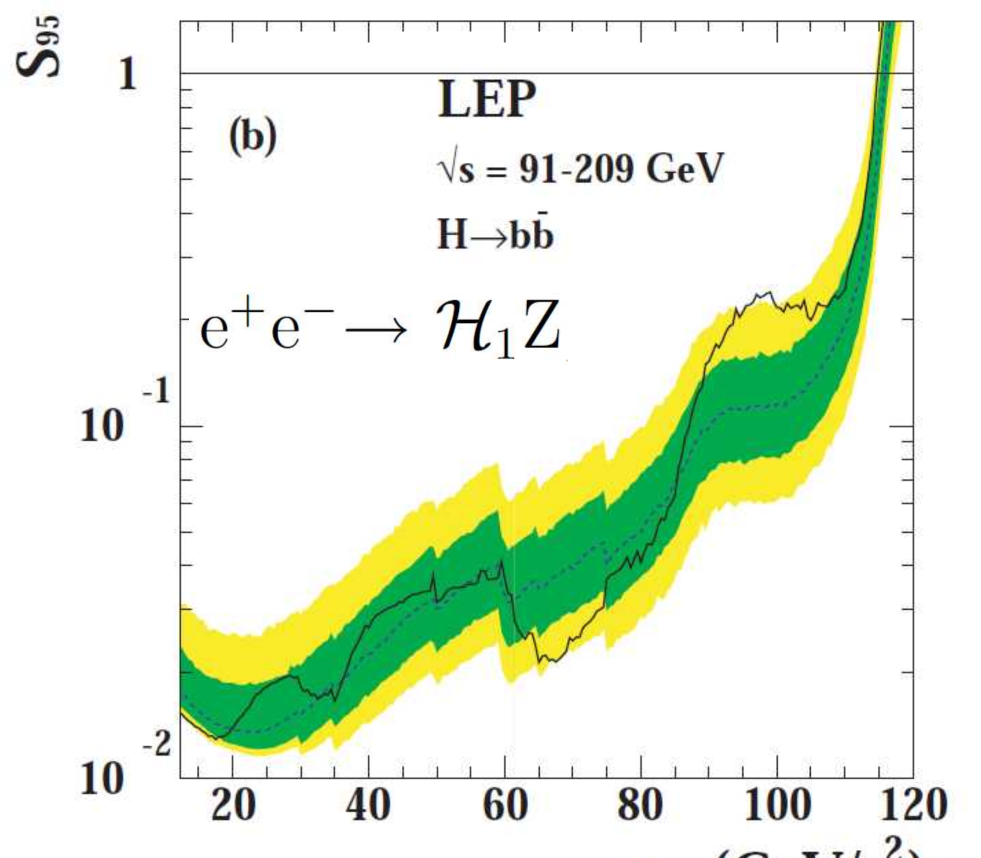
$\sin(\beta - \alpha)$



$\cos(\beta - \alpha)$

What do we know about MSSM Higgs boson?

$$S_{95} = \sigma_{max}/\sigma_{ref}$$



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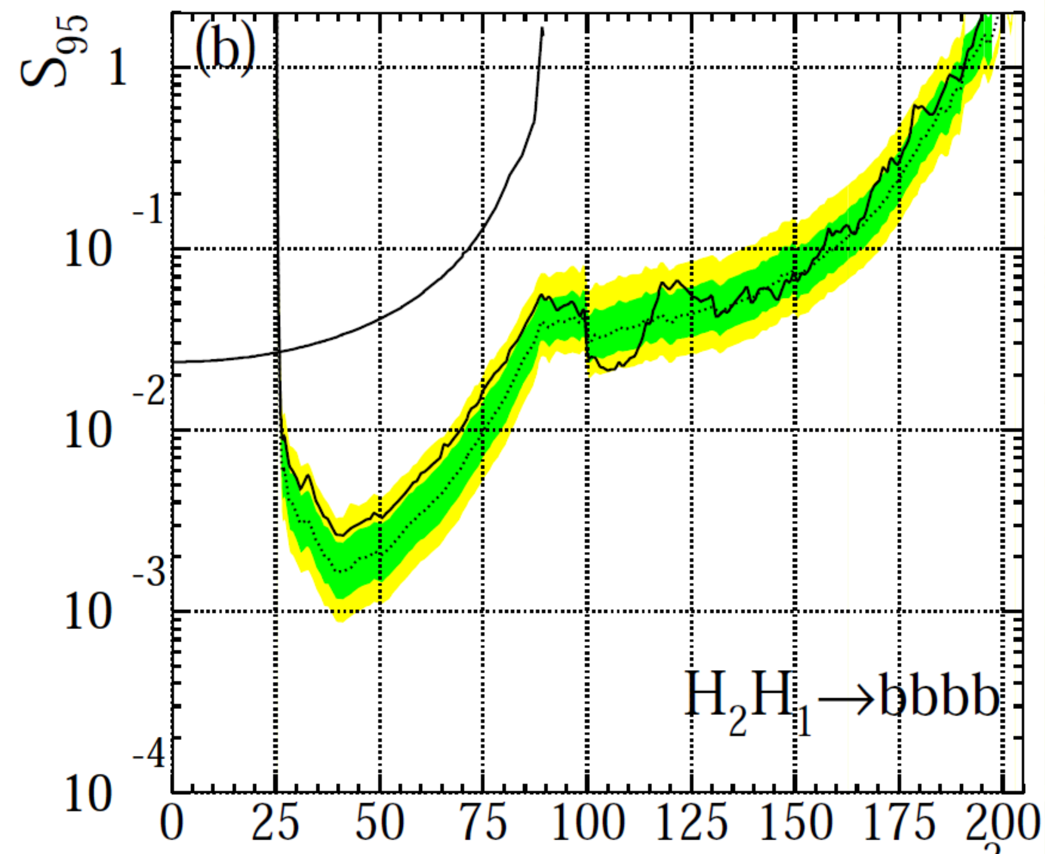

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Similar limits are for H->$\tau\tau$ channel,

but Br(H->$\tau\tau$) is one order of magnitude smaller then Br(H->bb)

Higgs mixing and radiative correcions

tree-level mixing matrix $\mathcal{M}^2$

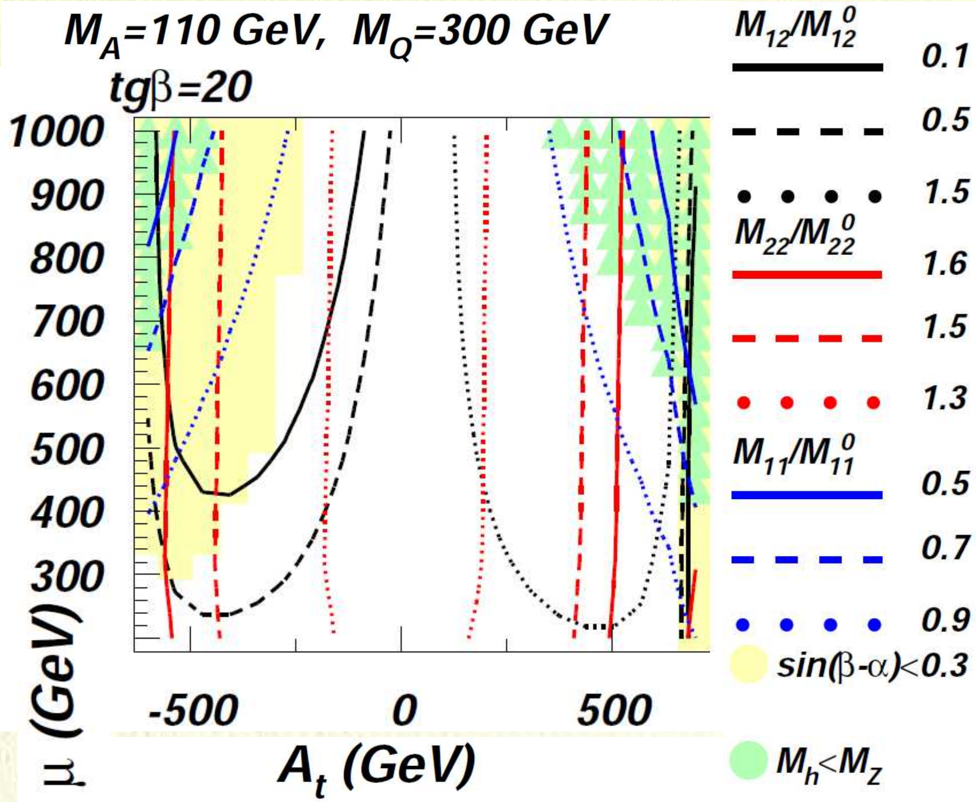
$$\begin{pmatrix} M_A^2 s_\beta^2 + M_Z^2 c_\beta^2 & -(M_A^2+M_Z^2)s_\beta c_\beta \\ -(M_A^2+M_Z^2)s_\beta c_\beta & M_A^2 c_\beta^2 + M_Z^2 s_\beta^2 \end{pmatrix}$$

diagonalized by Higgs mixing angle

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} -s_\alpha & -c_\alpha \\ c_\alpha & s_\alpha \end{pmatrix} \begin{pmatrix} Reh_d^0 \\ Reh_u^0 \end{pmatrix}$$

convention:

$$0 \le \beta \le \pi/2, \quad -\pi/2 \le \alpha \le 0$$



1-loop corrections

$$\delta\mathcal{M}_{11}^2 \propto -\tilde{\mu}^2(x_t^2 h_t^4 - a_b^2 h_b^4)$$

$$\delta\mathcal{M}_{12}^2 \propto -\tilde{\mu}[x_t h_t^4(6 - x_t a_t) + \tilde{\mu}^2 a_b h_b^4]$$

$$\delta\mathcal{M}_{22}^2 \propto h_t^4[12 ln\frac{M_S^2}{m_t^2} + x_t a_t(12 - x_t a_t)]$$
$$-\tilde{\mu}^4 h_b^4$$

- At large A_t and small M_A, $\delta\mathcal{M}_{12}^2$ cancels tree-level mixing $\rightarrow \cos(\alpha) \simeq 0, \quad sin(\beta-\alpha) \simeq 0$
- light Higgs aligned along h_d – does not receive large corrections
- at large μ $\mathcal{M}_{11}^2$ is suppressed!

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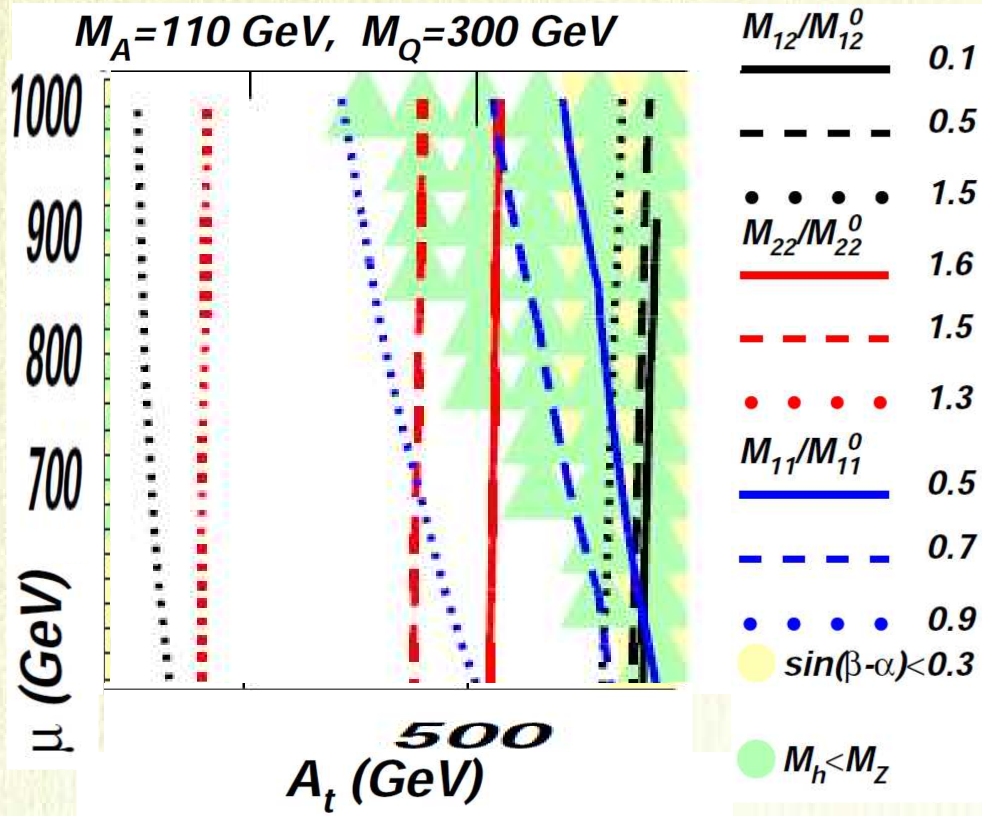

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If light Higgs boson preferred by nature, then how it could have escaped from LEP2 constraints?

- Let us check how light MSSM Higgs boson boson can be, escaping LEP2 constraints
- EW parameters scanned with CPsuperH

(Lee,Pilaftsis,Carena,Choi,Drees,Ellis,Wagner)

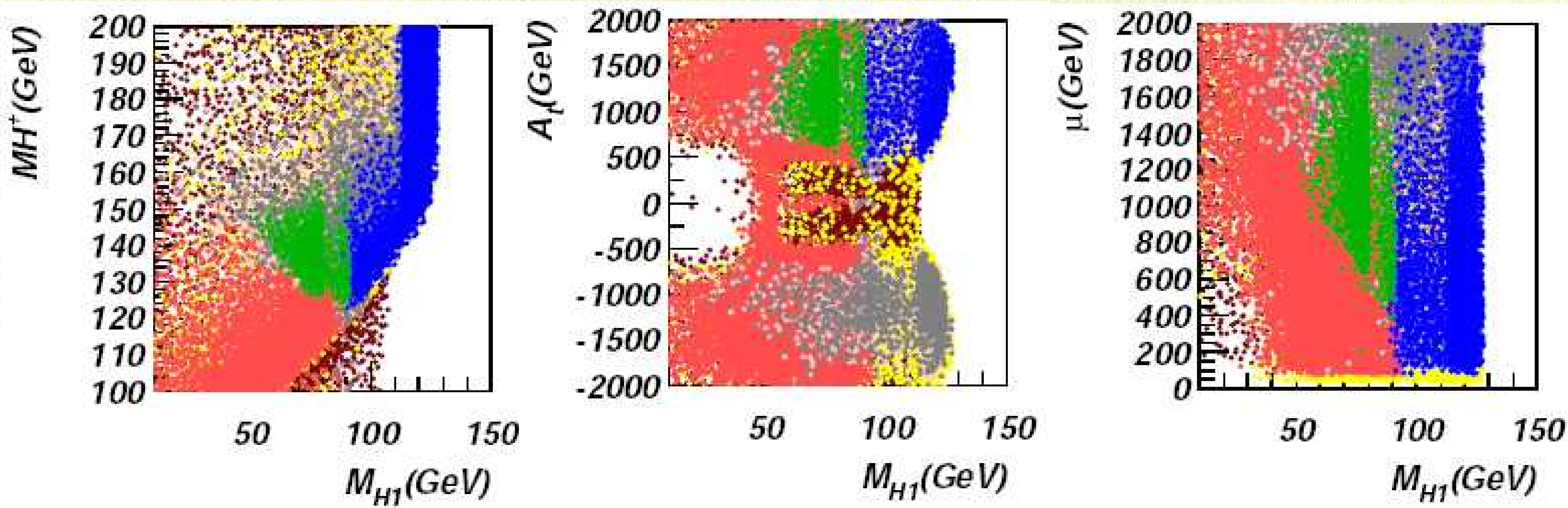
Parameter space, CP conserving case

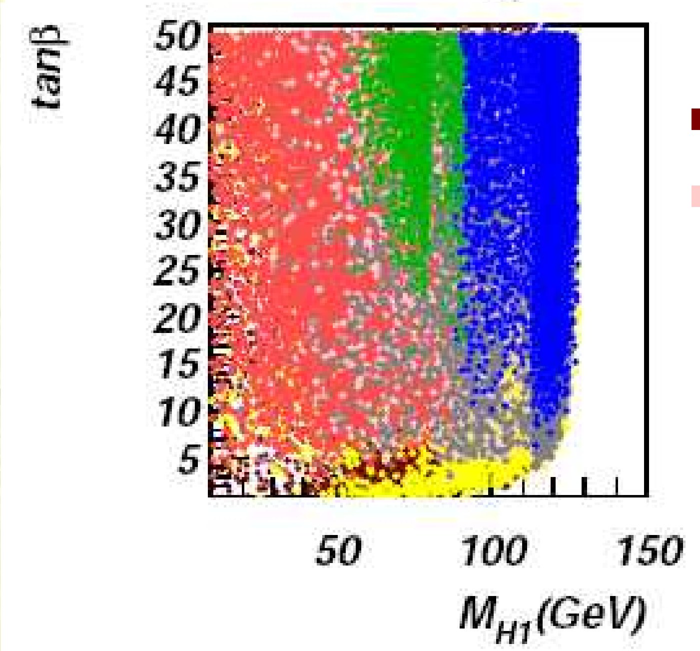
parameter	lower limit	upper limit
$\tan\beta$	1.1	50
M_{H^+}	100	200
μ	50	2000
M_1	50	500
M_2	50	500
M_3	50	1000
A_t	0	2000
$MQ3$	300	700

Constraints

LEPII $Z\mathcal{H}$ and $A\mathcal{H}$ constraint $\mathcal{H} = (h, H)$ $g^2_{ZZ\mathcal{H}} \times Br(\mathcal{H} \to b\bar{b}) < F_{Z\mathcal{H}}(M_\mathcal{H})$ $g^2_{ZZh} \times Br(A \to b\bar{b}) \times Br(H \to b\bar{b}) < F_{Ah}$ $g^2_{ZZH} \times Br(A \to b\bar{b}) \times Br(h \to b\bar{b}) < F_{AH}$
$M_{\chi^\pm_1} > 100$, $M_{\tilde{t}_1} > 100$
Color breaking constraints $\mu < 3m_{Q3}$, $A_t < 3m_{Q3}$
$\Delta\rho_{SUSY} < 2 \times 10^{-3}$
$b \to s\gamma$ SUSY constraint: $\|\Delta Br(b \to s\gamma)\| < 1 \times 10^{-4}$

Scan Results





excluded by:

- LEP2 ZH search
- LEP2 AH search
- LEP2 chargino search
- the color breaking constraint
- $BF(b \to s\gamma)$ constraint

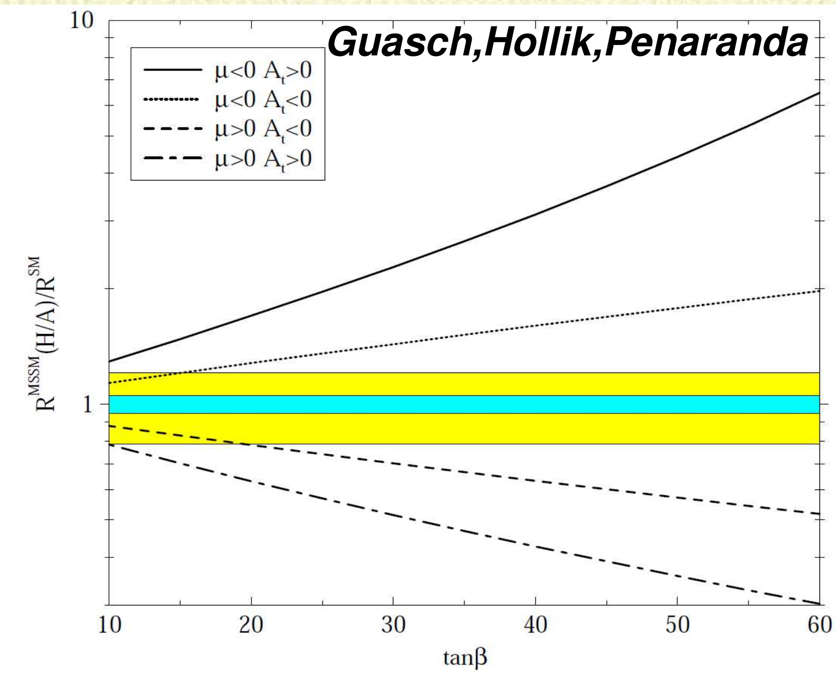
allowed:

- $M_{H1} > M_Z$
- $M_{H1} < M_Z$

Scan Results

- There are points with light Higgs boson in the 60-100 GeV range escaping LEPII ZH and AH search!
- No-lose 'theorem' does not work?
- There are SUSY corrections suppressing ττH and bbH couplings in non-universal way!

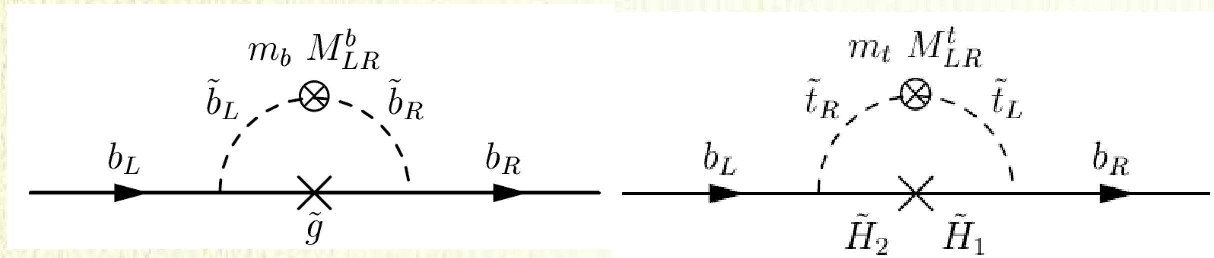
This is, actually well-studied and generic effect
(Carena,Mrenna,Wagner;Borzumati,Farrar,Polonsky; Guasch,Hollik,Penaranda)



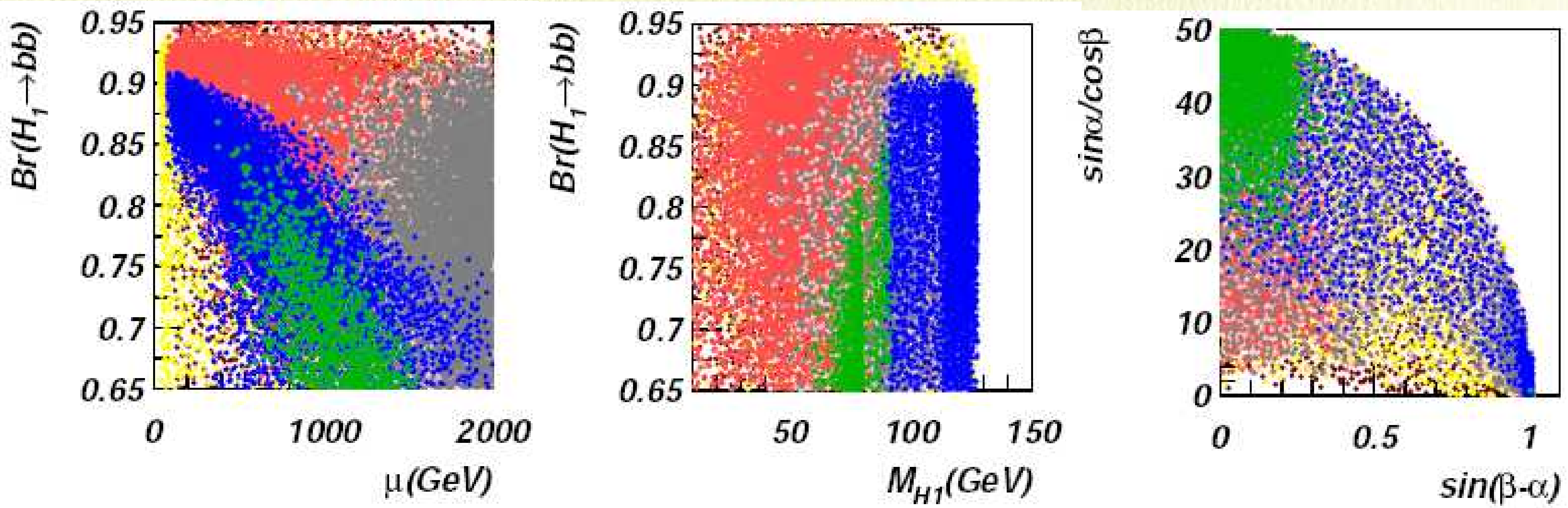
$$R = BR(H \to b\bar{b})/BR(H \to \tau^+\tau^-)$$

$$m_b + \delta m_b = \frac{m_b}{1+\Delta m_b}$$

$$(\Delta m_b)_{\mathrm{SUSY-QCD}} \propto + \frac{2\alpha_S(M_S)}{3\pi} m_{\tilde{g}}\, \mu \tan\beta$$



Effect of non-universal ττH and bbH SUSY corrections to H->bb partial decay width



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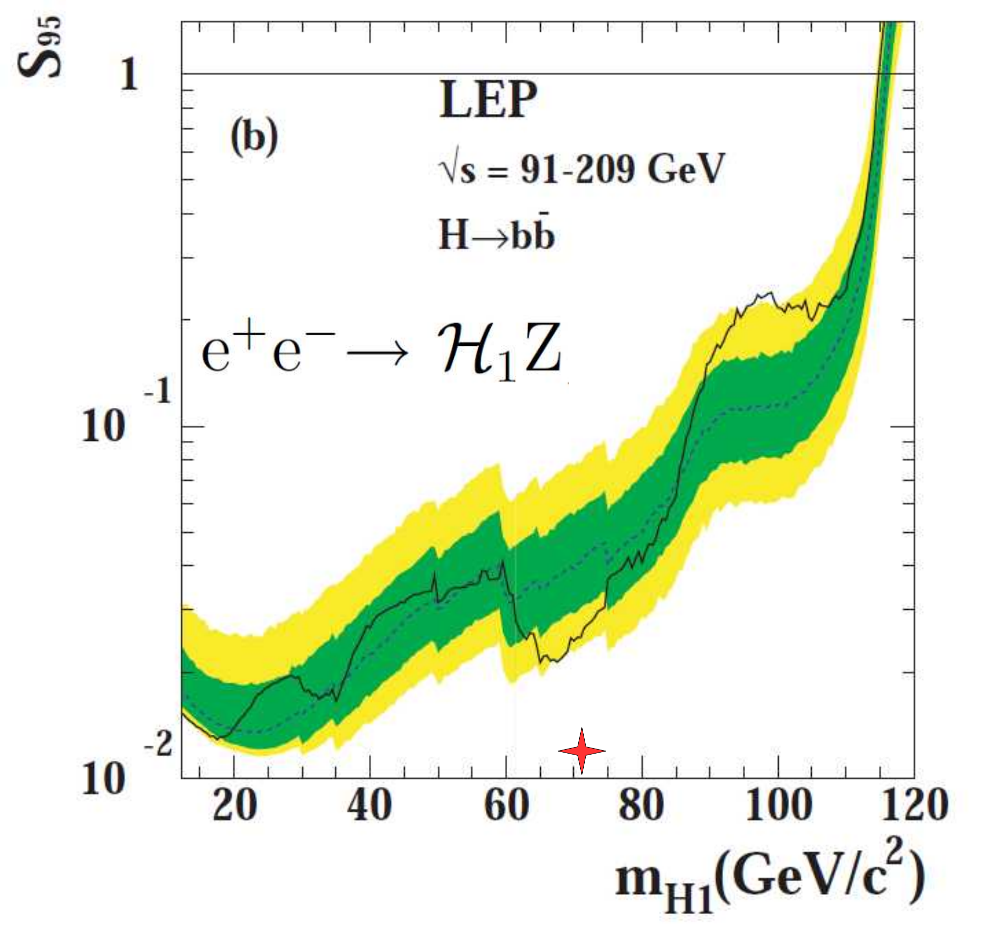
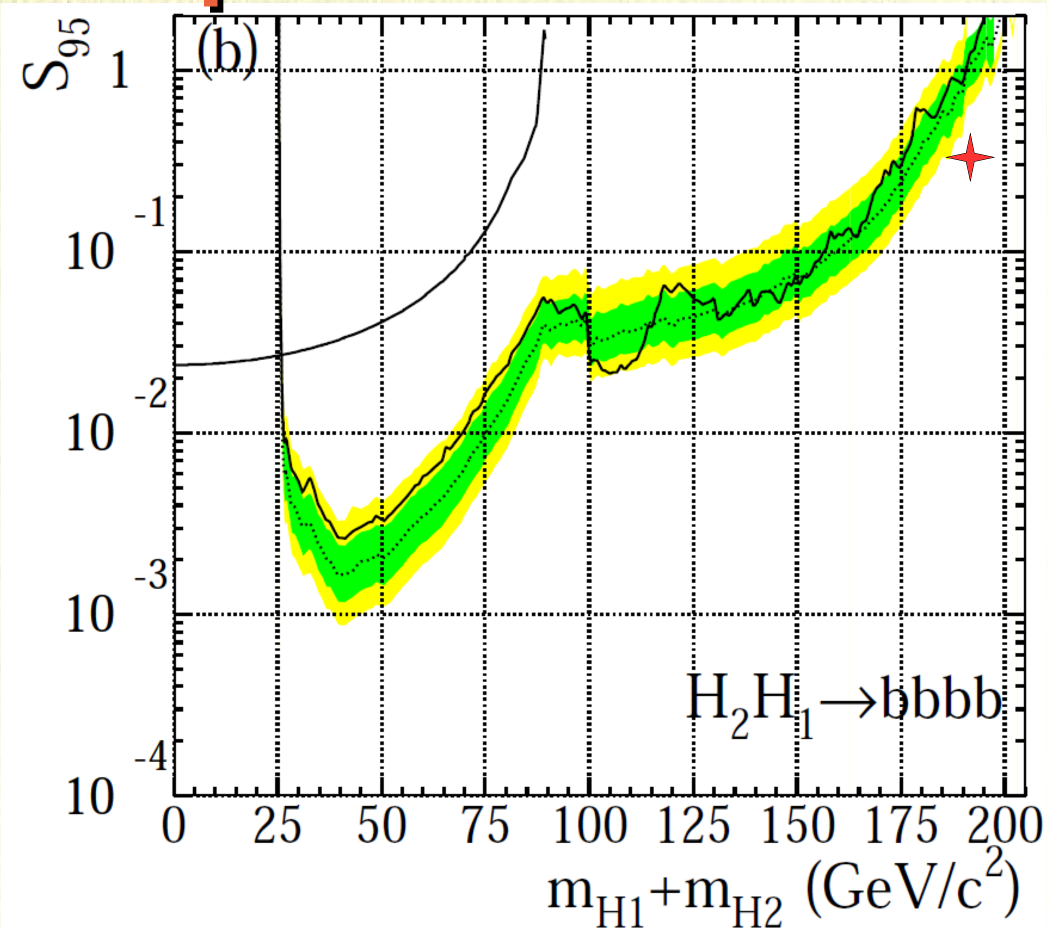
Lh benchmark point





$\tan\beta$	M_H^+	μ	A_t	M_1/M_2	M_3	M_Q
35	140	1000	1000	100/200	700	400

$\boldsymbol{M_h/M_A/M_H = 72/117/121}$ GeV

$Br(h/A/H \to b\bar{b}) = 0.67/0.65/0.73$

$g^2_{ZZh} = 0.011, g^2_{ZZH} = 0.98, \quad M_{\chi_1^+} = 198$ GeV, $M_{\tilde{t}_1} = 163$ GeV

$\Delta\rho = 0.9 \times 10^{-3}, \quad Br(b \to s\gamma) = 3.9 \times 10^{-4}$

$\sigma_{Zh}/\sigma^{exp}_{Zh} = 0.28, \quad \sigma_{Ah}/\sigma^{exp}_{Ah} = 0.52$

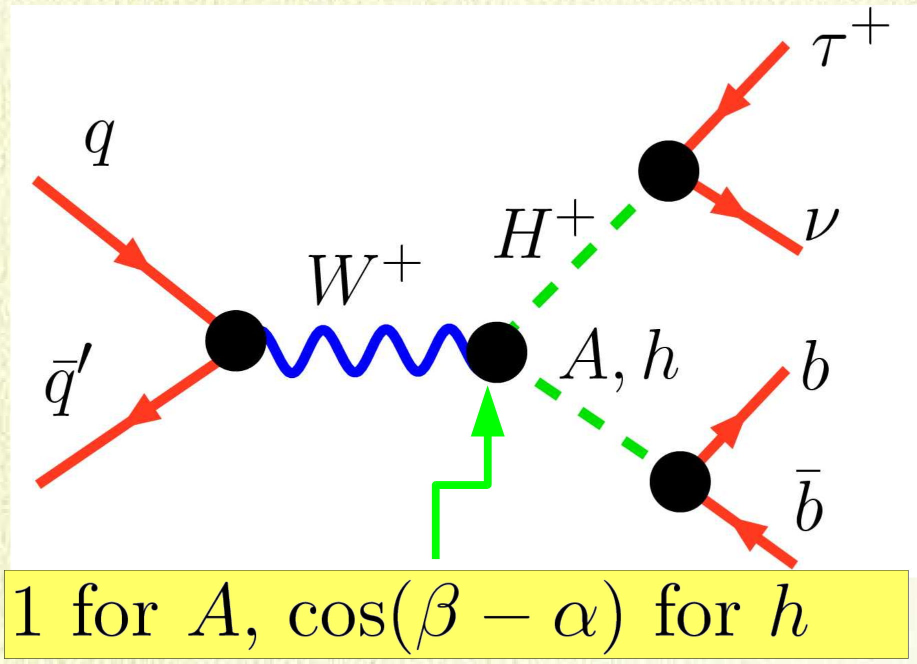
Generic features of the scenario

- Light Charged Higgs –
essential non-decoupling regime –
small ZZh coupling and large $WH^{+}h$ coupling,
Z-boson recoil Higgs constraints are safe
- Intermediate – large μ and A_t
- Large $\mu>0$ and heavy gluino providing non-universal corrections to tau and bottom Yukawa couplings and suppressing Higgs partial decay width to bb
- Light stop and chargino, intermediate-high $\tan\beta$ to cancel O(SM) H^{+} contribution to $b \to s\gamma$ ($A_t > 0$).

One more part of the exciting phenomenology!

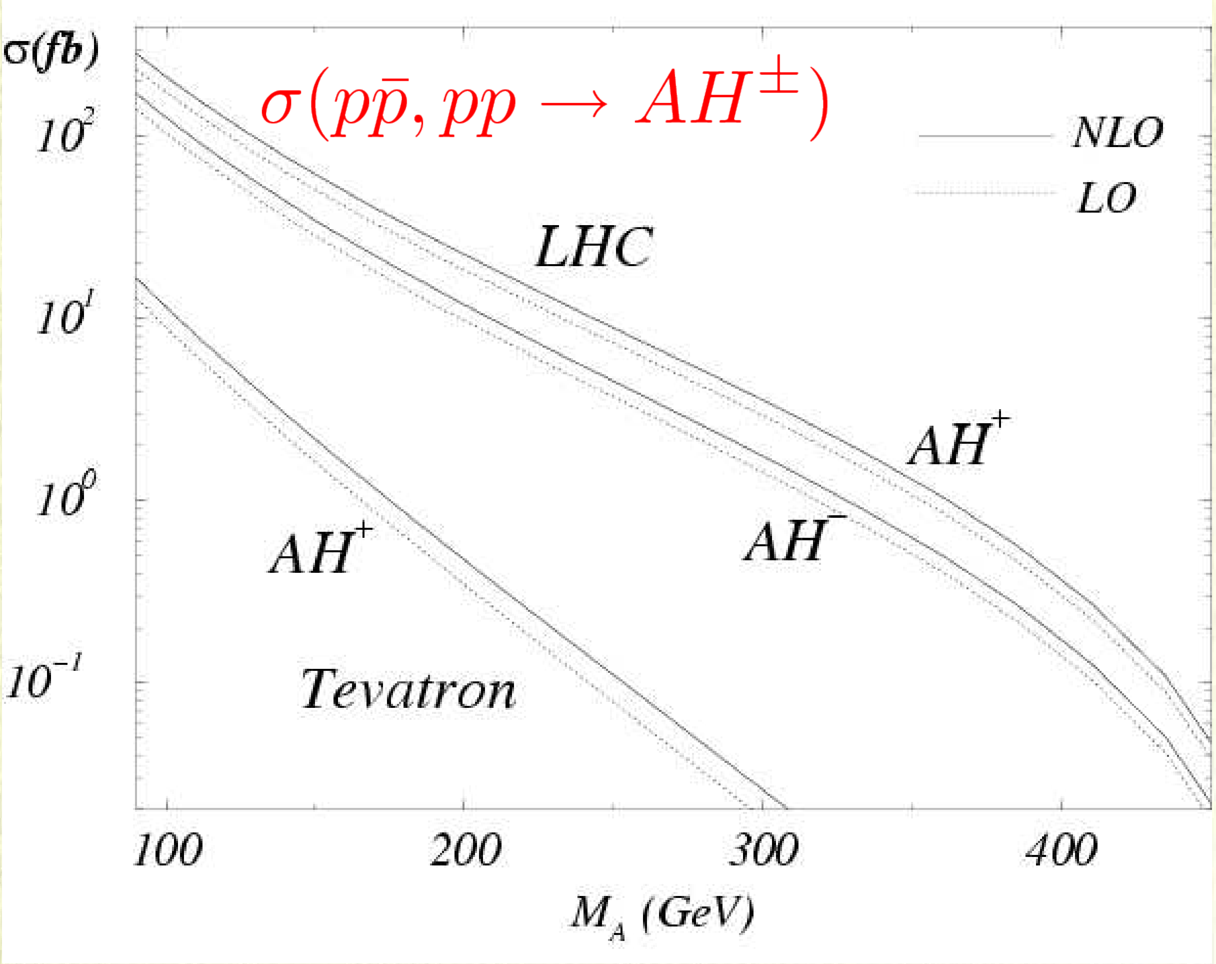
Associated production of Charged – Neutral Higgses as a test of the light Higgs scenario

- small ZZh coupling and large WH^+h coupling scenario makes H^+h or/and H^+A associate production very special: complementary to LEPII



- $g_{AH^+W^-} = 1$ and does not depend on SUSY parameters at tree-level

$H^{+}A$ signal rate



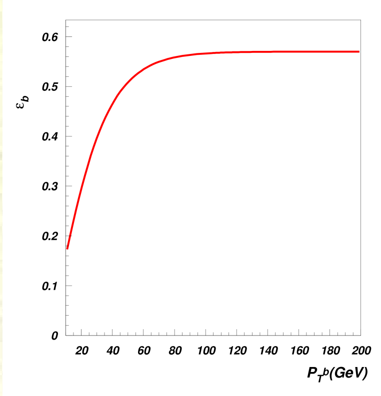
Q.-H. Cao, S. Kanemura, C.-P. Yuan
hep-ph/0311083

NLO QCD correction is about 20%

Signal versus background study

- $q\bar{q} \to W^* \to A(\to b\bar{b})H^+(\to \tau^+\nu)$ process
- we only consider the $\pi^+\nu$ decay mode of τ^+
- $b\bar{b}\pi^+ \; \not{E}_T$ signature
- backgrounds:

$$q\bar{q}' \to W^+ b\bar{b}, \quad q\bar{q}' \to t\bar{b},$$
$$q\bar{q} \to t\bar{t}, \quad qg \to q' t\bar{b}$$



- Realistic b-tagging efficiency: $\varepsilon_b = 0.57 \times \tanh\left(\frac{p_T^b}{35\,\text{GeV}}\right)$
- Basic cuts:

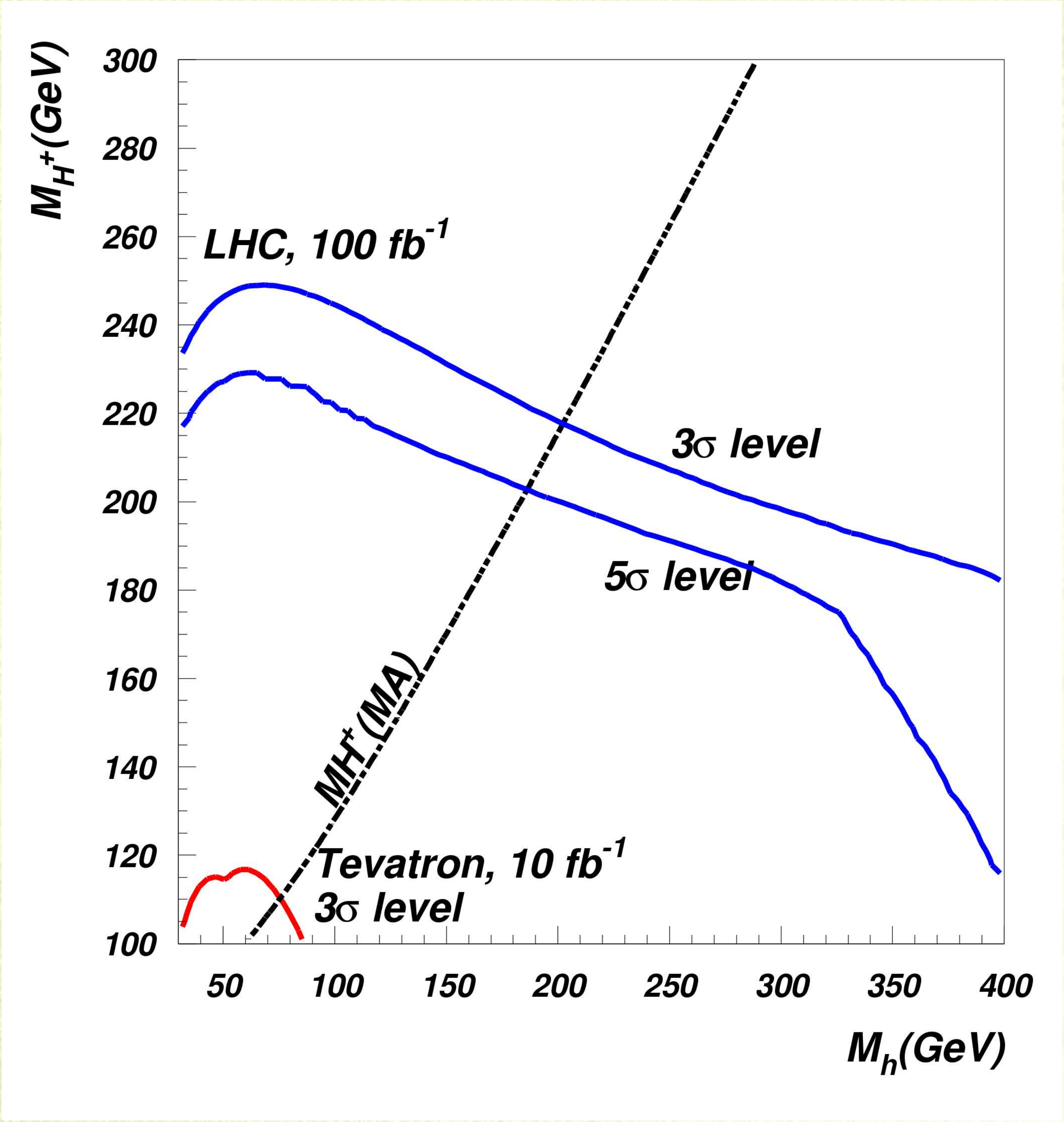
$$P_T(b,\bar{b},\pi^+) > 15\,\text{GeV}, \quad |\eta(b,\bar{b},\pi^+)| < 3.5, \quad \Delta R(b,\bar{b},\pi^+) > 0.4$$

+ veto for jets and leptons in the central region:

$$p_T(\text{lepton}) > 10\,\text{GeV}, \text{and } |\eta(\text{lepton})| < 3$$
$$p_T(\text{jet}) > 10\,\text{GeV}, \text{and } |\eta(\text{jet})| < 3.5$$

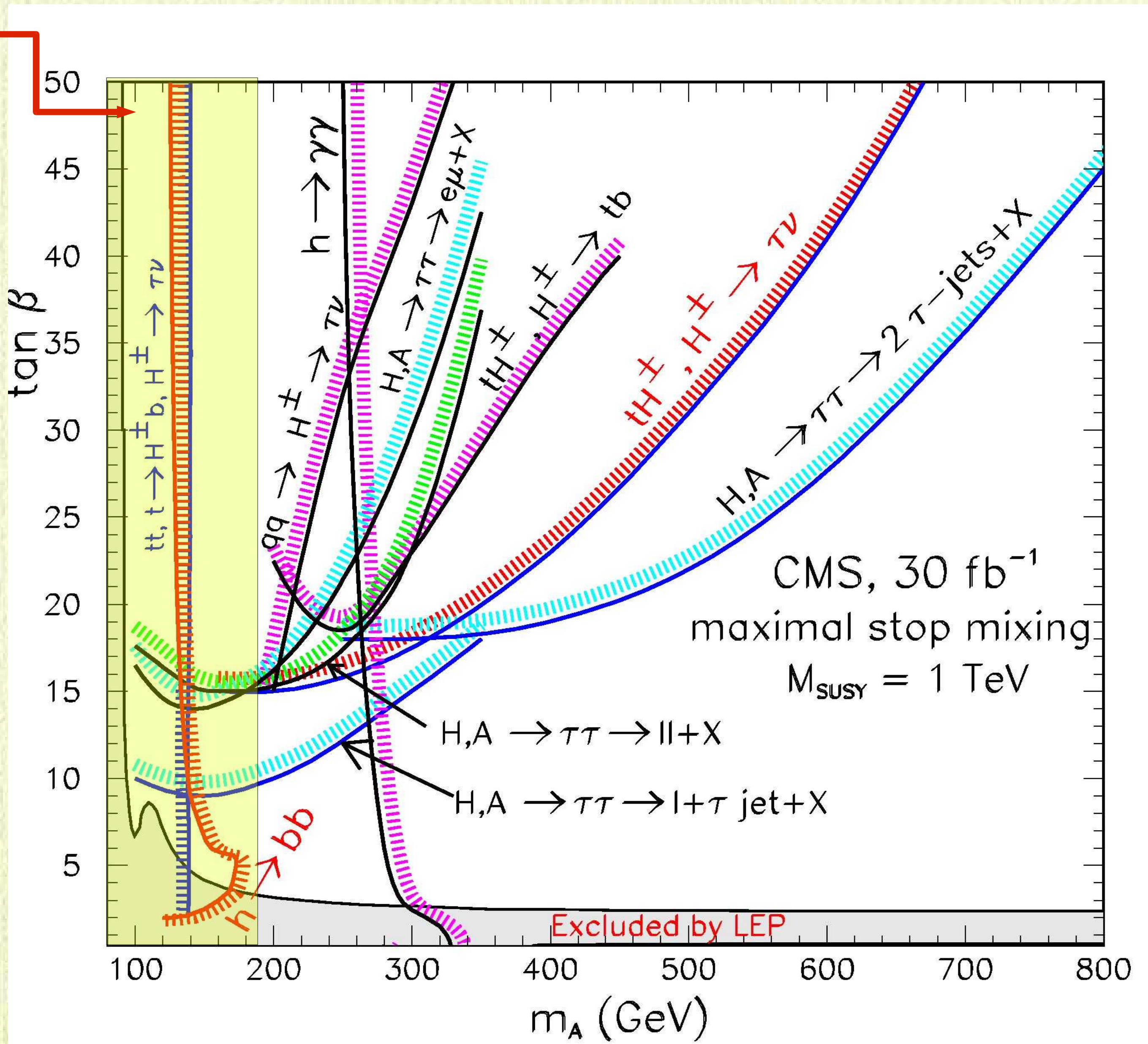
- Hard cuts: $\not{E}_T > 50\,\text{GeV}, \quad p_T^\pi > 40\,\text{GeV}, \quad |m_{b\bar{b}} - m_A| < 10\,\text{GeV}$

Tevatron/LHC reach for H^+A



Projecting on to tanβ – M_A plane

H⁺A



Conclusions

- **Light MSSM Higgs ~ 60 GeV mass is possible.**
  It is realized at M_{H+} ~ 130-140 GeV due to large SUSY corrections to Higgs mixing and due to non-universal SUSY corrections to bottom and tau-mass at for A_t and μ>400 GeV. It suggests reanalyzing LEP data by combining bb and $\tau\tau$ channels together.
- **The straightforward test is the search for H^+A LHC cover the whole Lh parameter space – complementary to LEP2**
- **Possible solution for SUSY fine-tuning problem? It also perdicts an exciting phenomenology: light stops and charginos.**
- **LHC has a great potential for probing the H^+A even for heavy A: independent of $\tan\beta$!**