The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

2045-13

Joint ICTP-INFN-SISSA Conference: Topical Issues in LHC Physics

29 June - 2 July, 2009

Light Higgs Bosons Beyond the Standard Model

Radovan DERMISEK
Indiana University
USA

Light Higgs bosons beyond the Standard Model

Radovan Dermisek

Indiana University, Bloomington

R.D., arXiv:0806.0847 [hep-ph], arXiv:0807.2135 [hep-ph]

R.D. and J. Gunion, arXiv:0811.3537 [hep-ph]

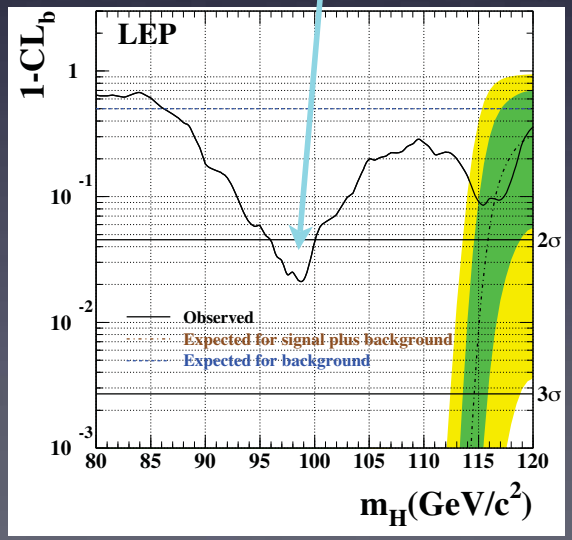
related to a series of papers with J. Gunion

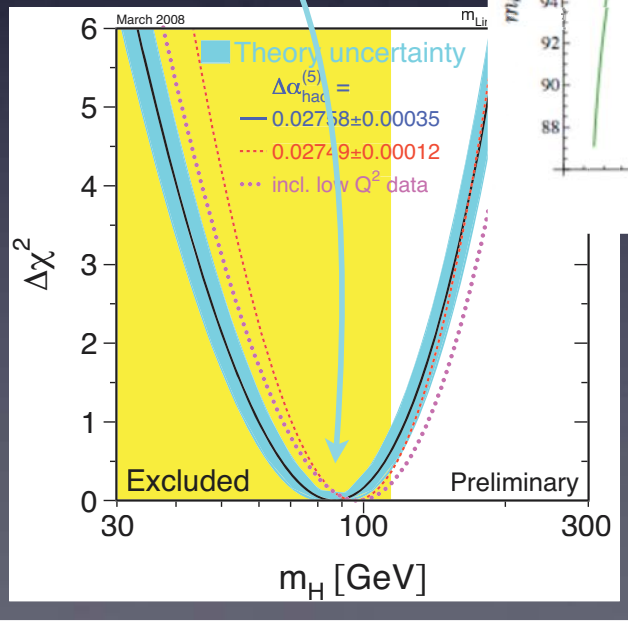
Outline:

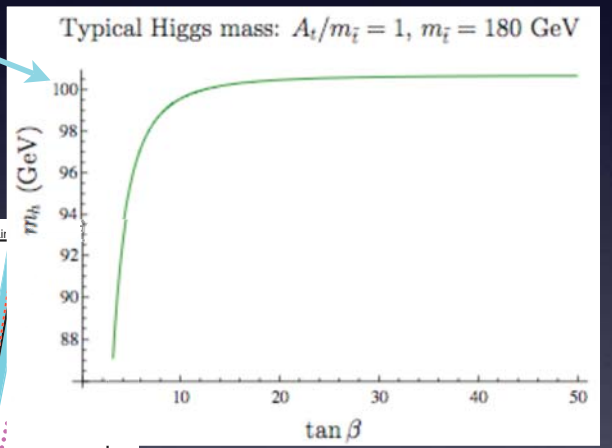
- motivation for non-standard Higgs decays
- NMSSM with a light singlet-like CP-odd Higgs
- MSSM-like models with many light Higgses: h, H, A, $H^{\pm}$
  - NMSSM example
- summary of related Higgs decay modes
  - review of experimental searches and theoretical studies
  - never-searched-before decay modes, possible searches...

Motivation for modified Higgs decays:

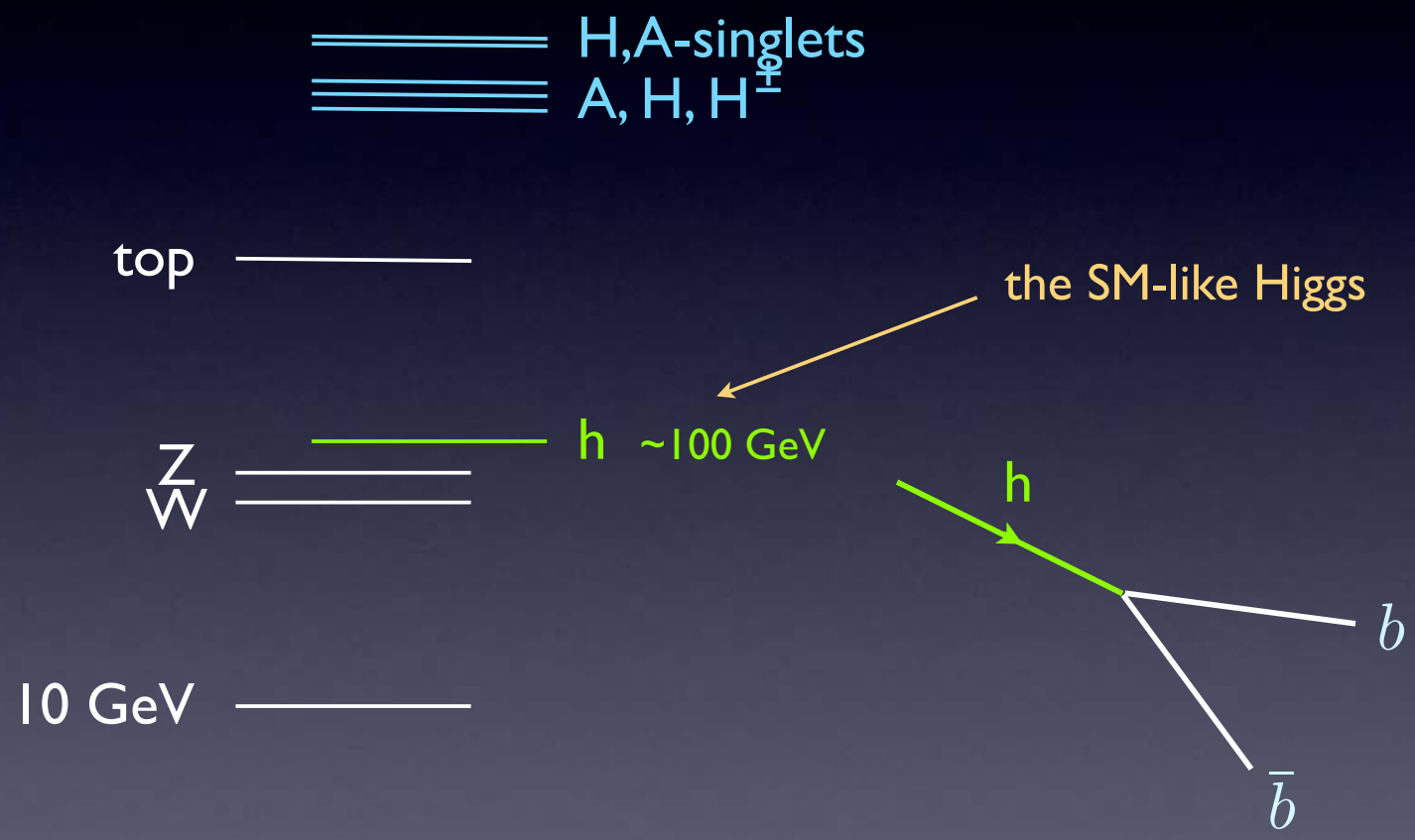
- arise in many models beyond the SM
- allow the SM-like Higgs significantly below LEP limits
  - wanted by generic SUSY/natural EWSB
  - preferred by precision EW data
  - indicated by LEP data







(N)MSSM - the usual story (decoupling limit)



NMSSM - brief review

MSSM + one additional singlet superfield (results in one CP-even and one CP-odd neutral Higgs bosons, and one additional neutralino):

$$W = W_{MSSM} + \lambda \, \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3} \, \widehat{S}^3$$

$$\mathcal{L}^{SSB} = \mathcal{L}^{SSB}_{MSSM} + \lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3 + m_S^2 S S^*$$

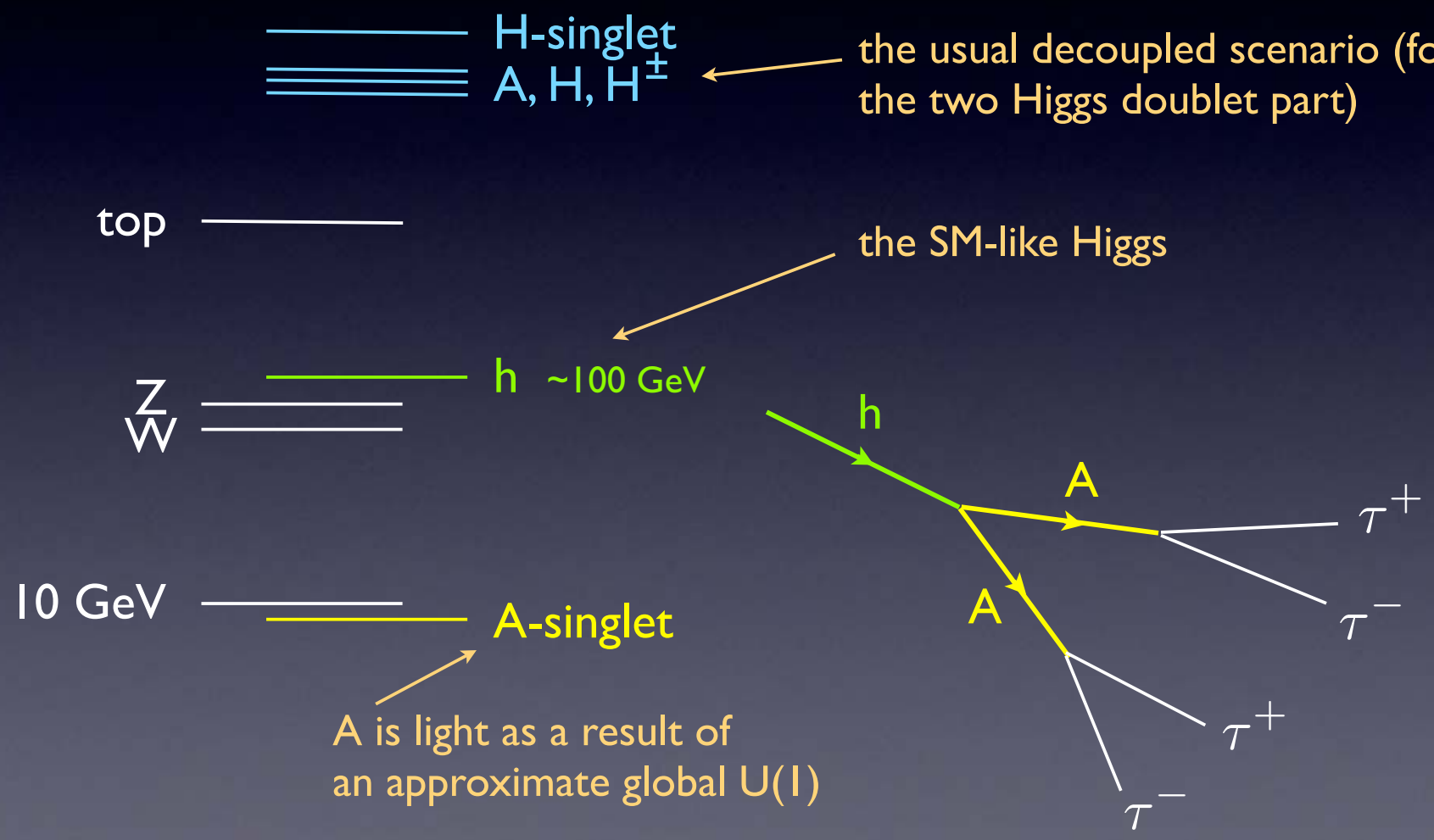
$$\tan\beta = \frac{v_u}{v_d}, \quad \mu_{eff} = \lambda s$$

Higgs mass at tree level:

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + M_Z^2 \frac{2\lambda^2}{g_2^2 + g'^2} \sin^2 2\beta$$

NMSSM with a light singlet CP odd Higgs

R.D. and J. Gunion (2005)



NMSSM - brief review

MSSM + one additional singlet superfield (results in one CP-even and one CP-odd neutral Higgs bosons, and one additional neutralino):

$$W = W_{MSSM} + \lambda \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3}\widehat{S}^3$$

$$\mathcal{L}^{SSB} = \mathcal{L}^{SSB}_{MSSM} + \lambda A_\lambda S H_u H_d + \frac{\kappa}{3} A_\kappa S^3 + m_S^2 S S^*$$

$$\tan\beta = \frac{v_u}{v_d}, \quad \mu_{eff} = \lambda s$$

Light CP odd Higgs:

$$C_{a_1 b\bar{b}} = \cos\theta_A \tan\beta$$

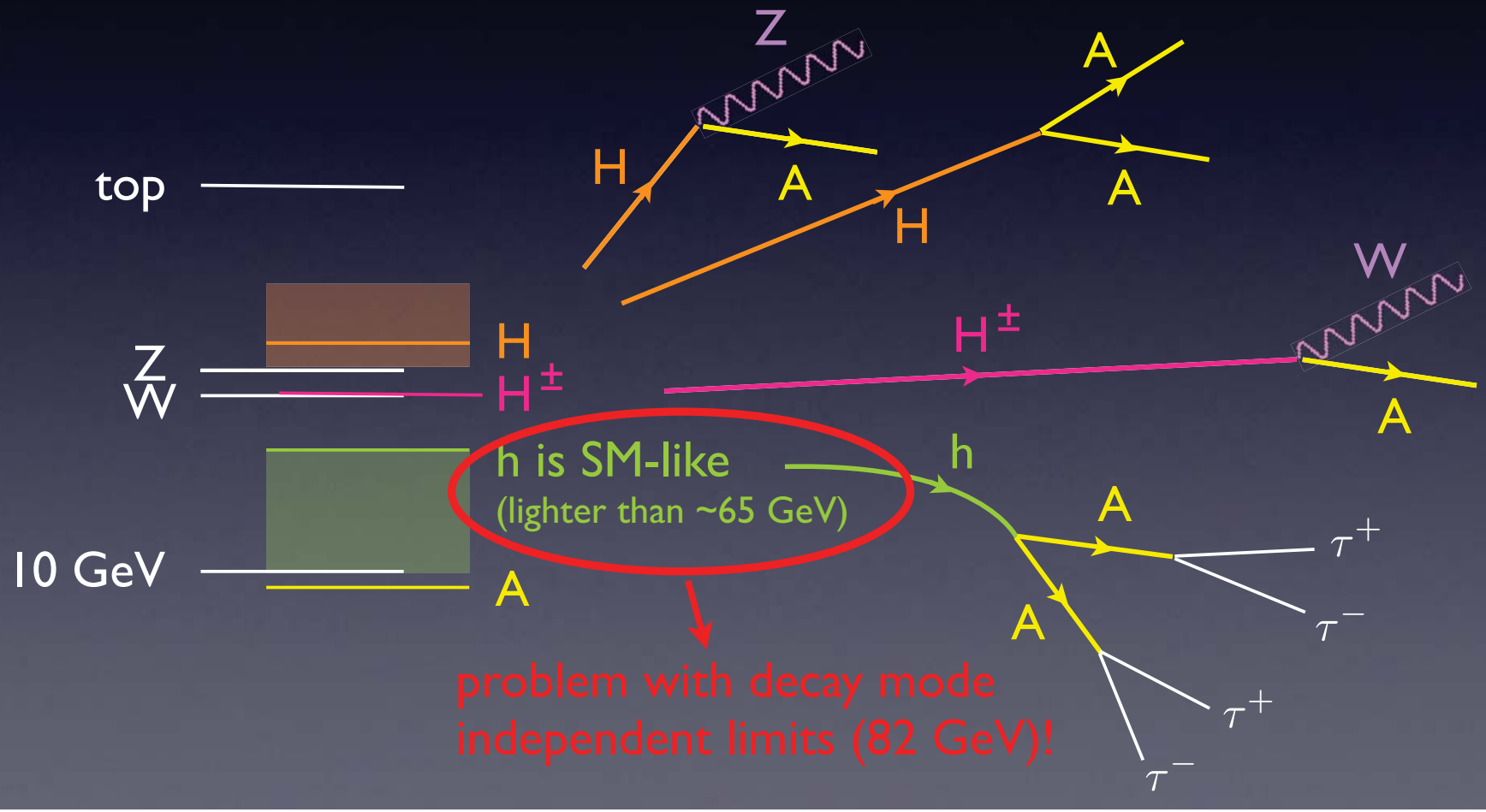
$$m^2_{a_1} \simeq 3s\left(\kappa A_\kappa \sin^2\theta_A + \frac{3\lambda A_\lambda \cos^2\theta_A}{2\sin 2\beta}\right)$$

$$a_1 \equiv \cos\theta_A\, a_{MSSM} + \sin\theta_A\, a_S\,, \qquad \cos\theta_A \simeq \frac{2v}{s\tan\beta}$$

Models with an MSSM-like light CP odd Higgs

R.D., arXiv:0806.0847 [hep-ph]

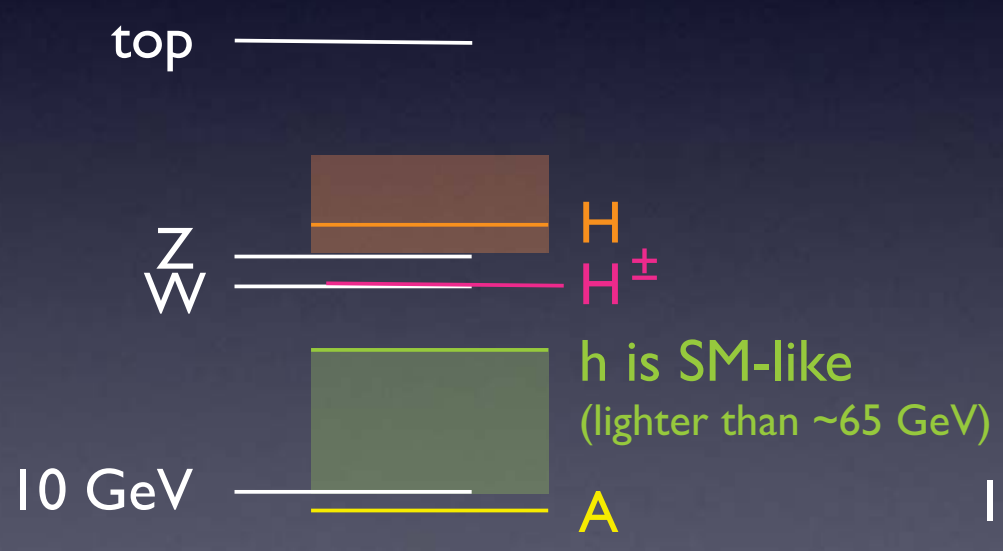
MSSM with $\tan\beta \lesssim 2.5$:



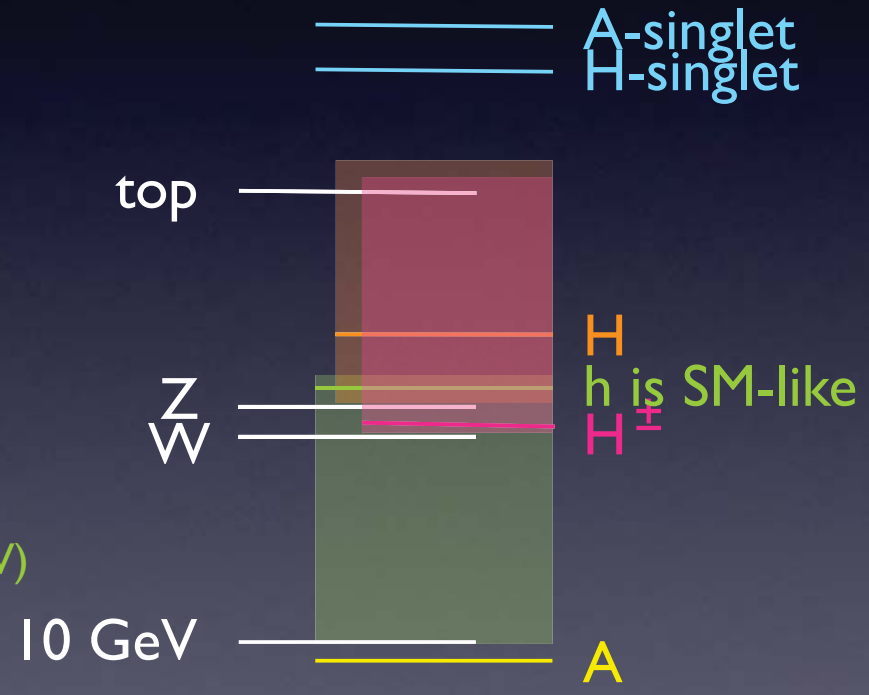
Models with an MSSM-like light CP odd Higgs

R.D., arXiv:0806.0847 [hep-ph], R.D. and J. Gunion, arXiv:0811.3537 [hep-ph]

MSSM with $\tan\beta \lesssim 2.5$:



NMSSM with $\tan\beta \lesssim 2.5$:



NMSSM provides an additional contribution to the mass of the SM-like Higgs:

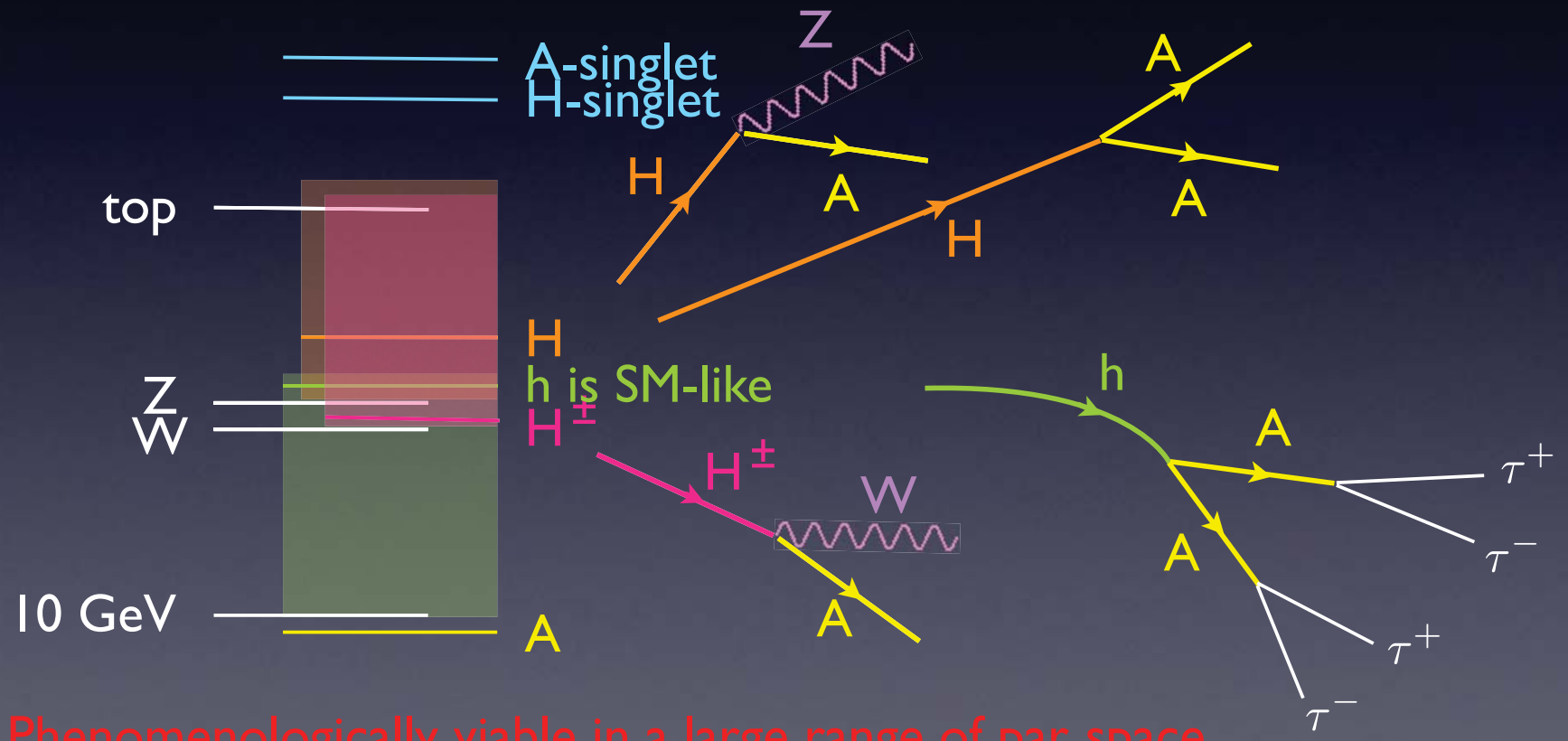
$$W \supset \lambda S H_u H_d$$

$$m_h^2 \simeq \cdots + \lambda^2 v^2 \sin^2 2\beta + \ldots$$

Models with an MSSM-like light CP odd Higgs

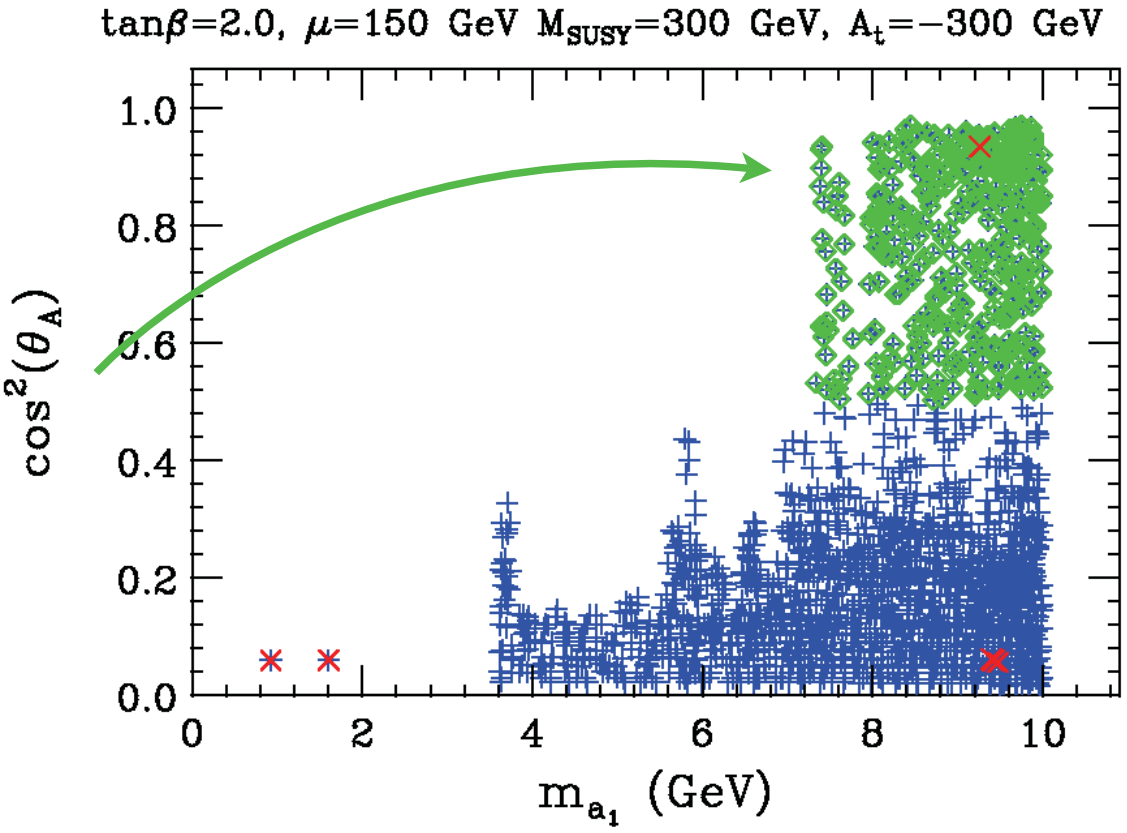
R.D., arXiv:0806.0847 [hep-ph], R.D. and J. Gunion, arXiv:0811.3537 [hep-ph]

NMSSM with $\tan\beta \lesssim 2.5$:



Phenomenologically viable in a large range of par. space
(no need for heavy SUSY), all Higgses produced already at LEP!

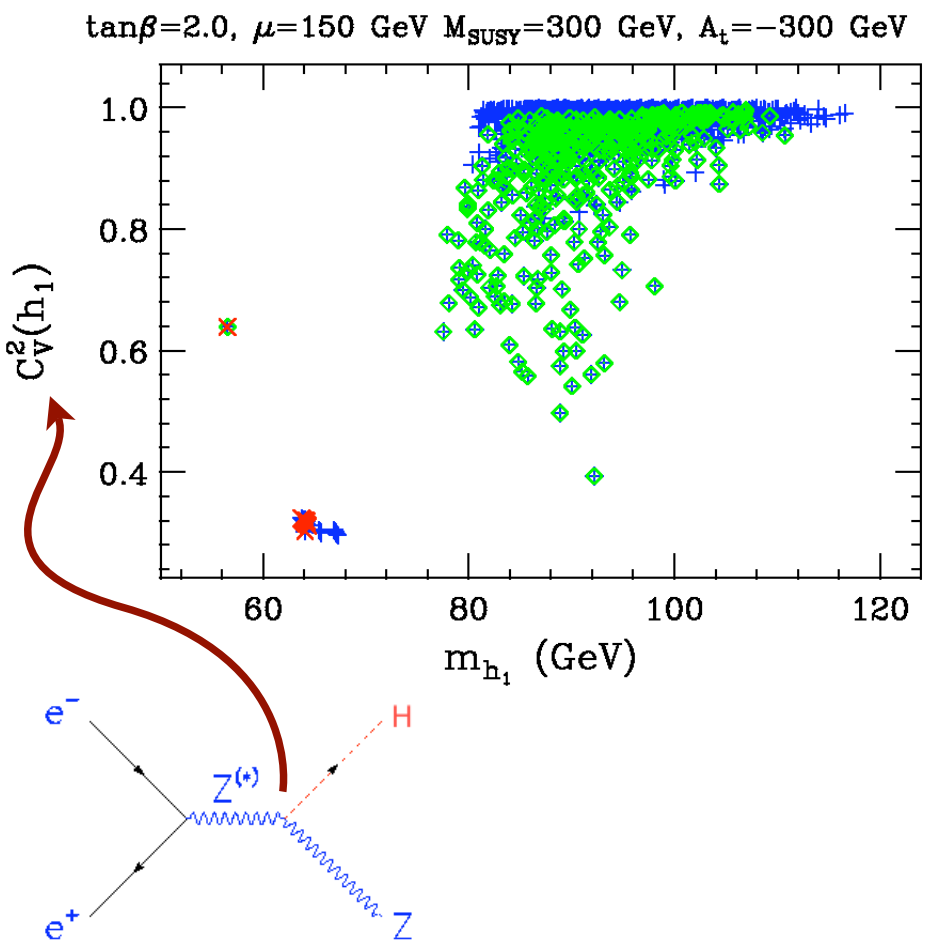
NMSSM with a light doublet-like CP-odd Higgs:

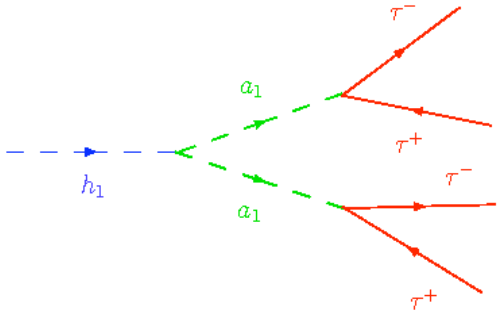


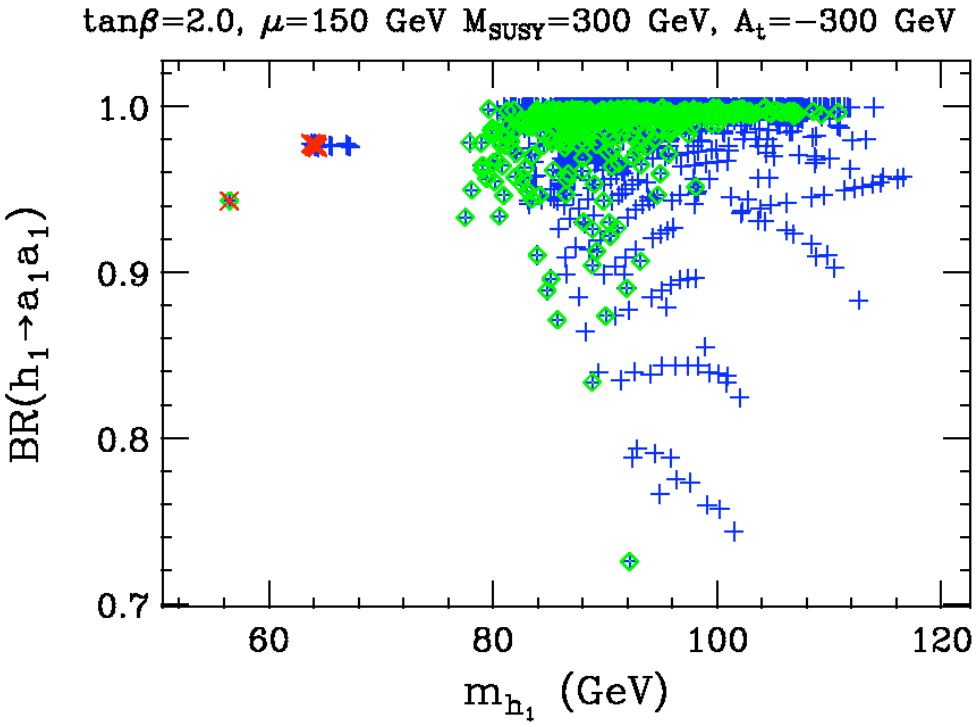
$$a_1 \equiv \cos\theta_A \, a_{MSSM} + \sin\theta_A \, a_S$$

$$C_{a_1 b\bar{b}} = \cos\theta_A \tan\beta$$

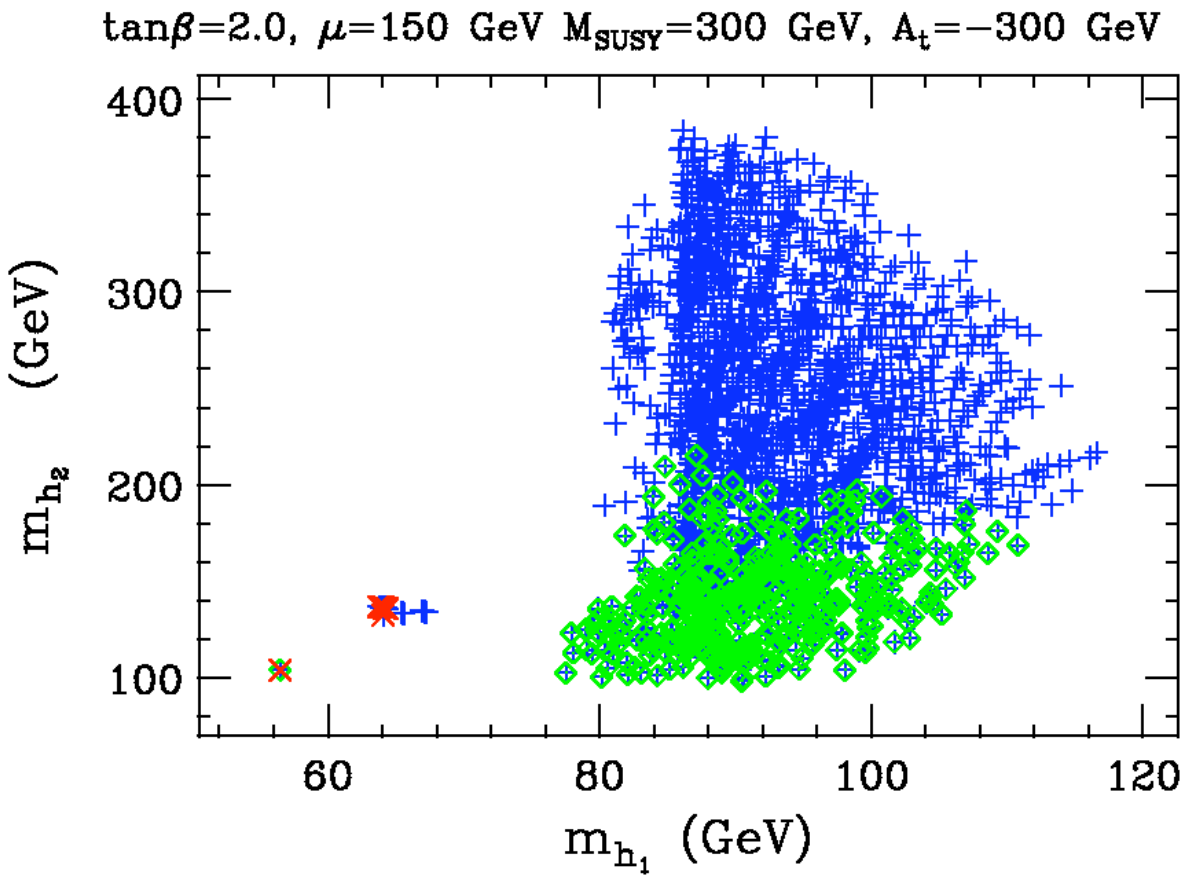
SM-like CP-even Higgs:



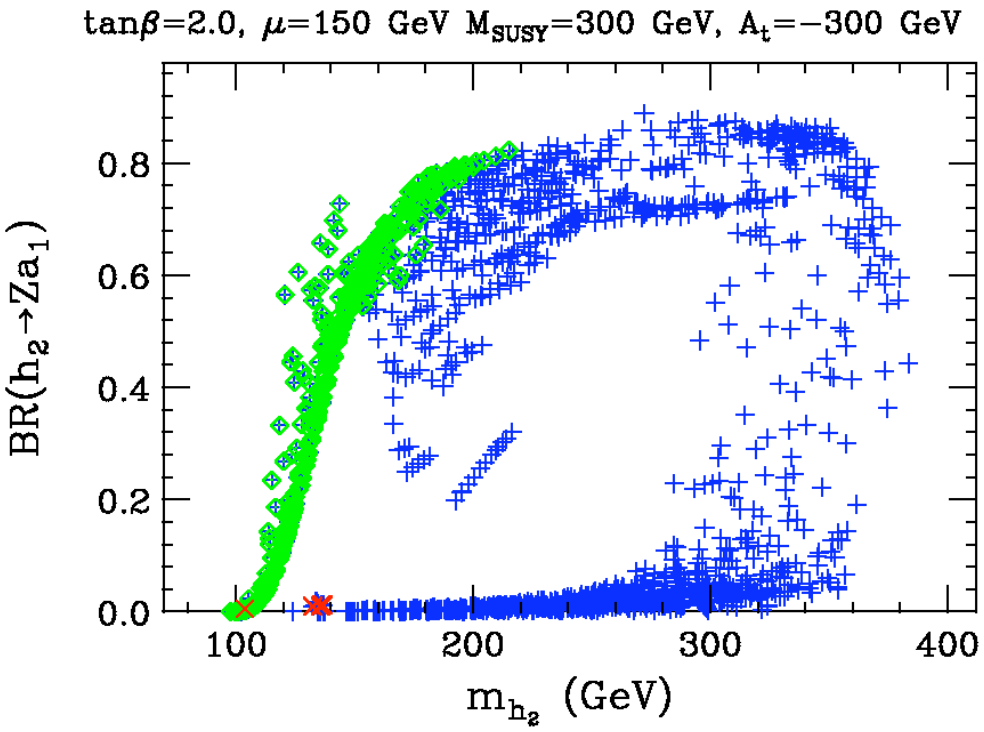


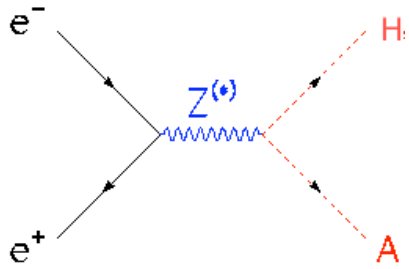


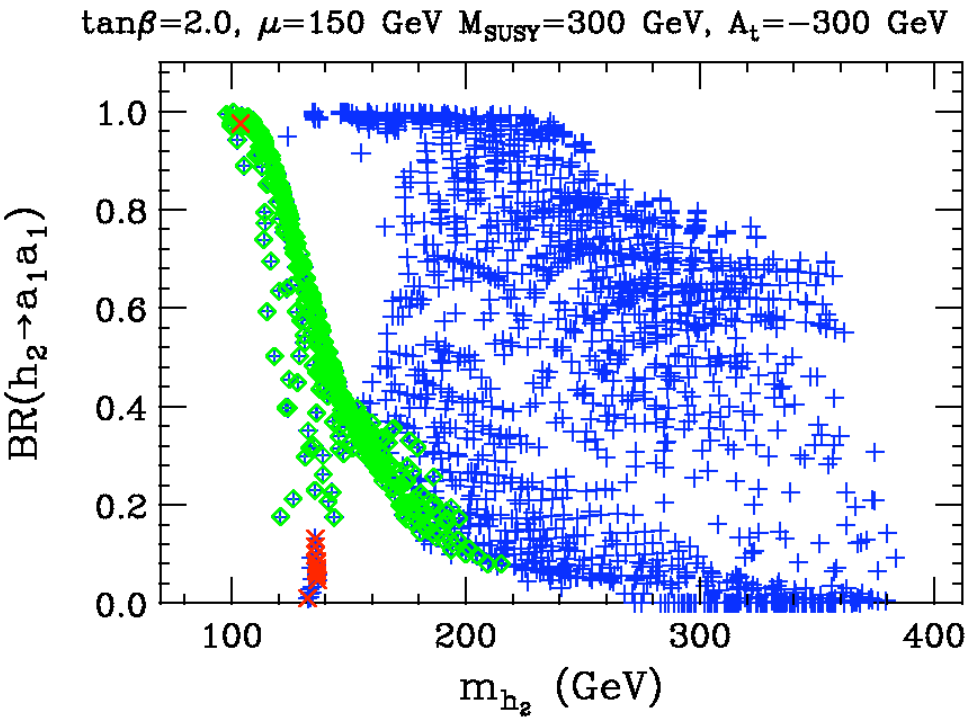
Heavy CP-even Higgs:



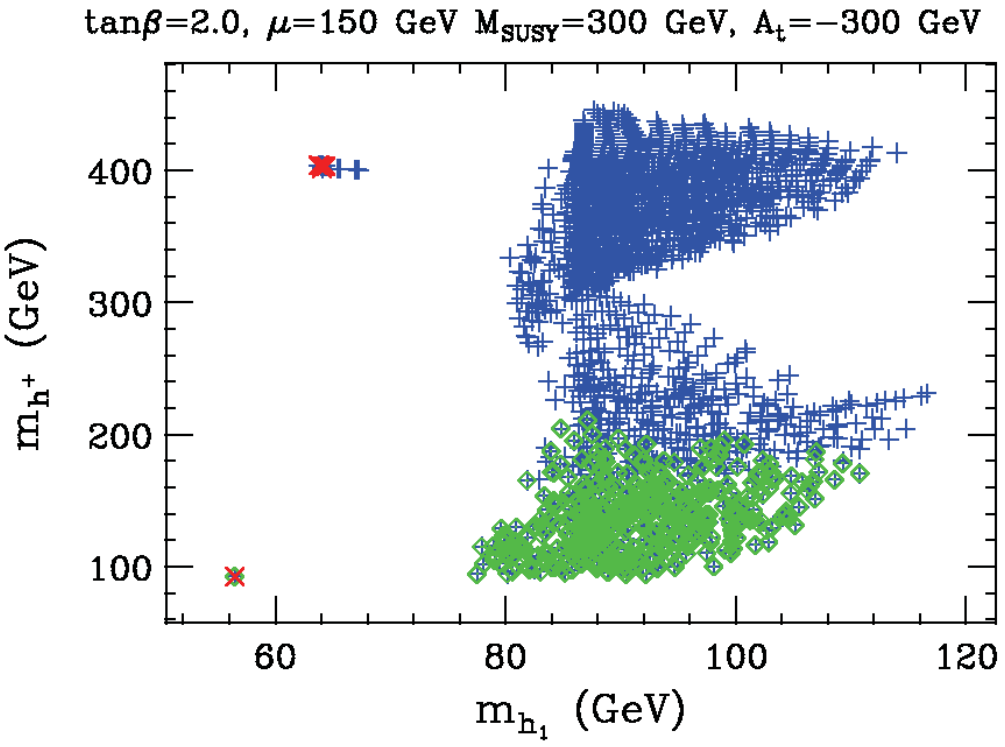
Heavy CP-even Higgs:

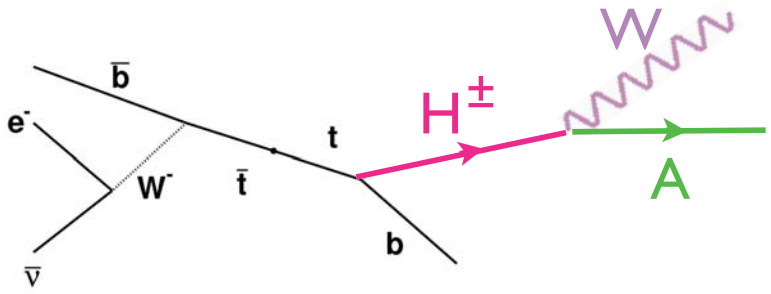


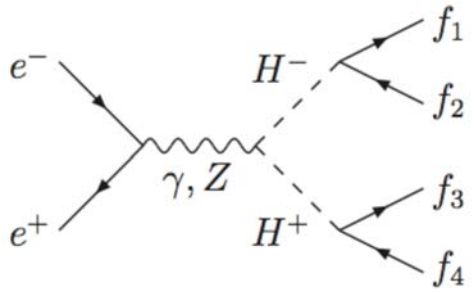




Charged Higgs:

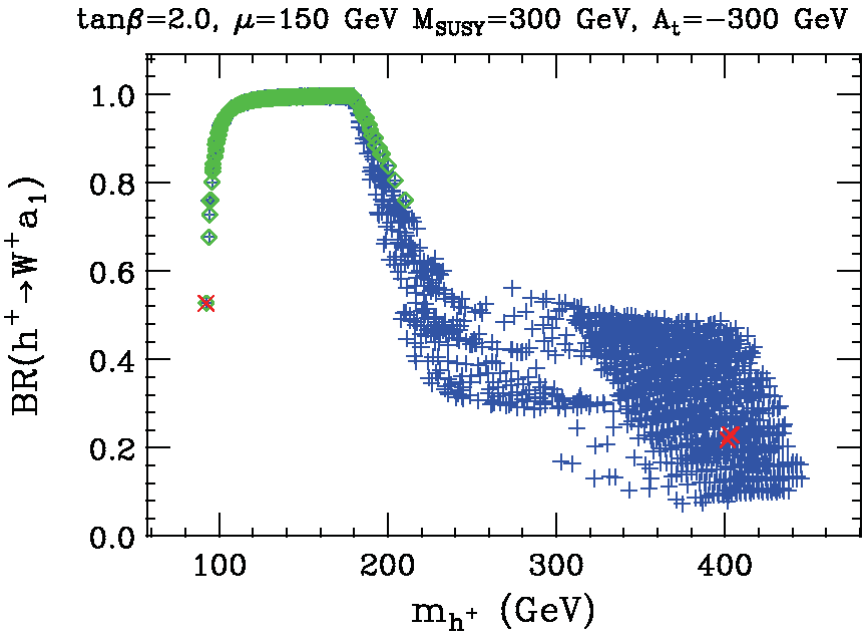






if $m_{H^\pm} \simeq m_{W^\pm}$, it would contribute to the measurement of the lepton universality in W decays, there is a 2.8σ deviation!

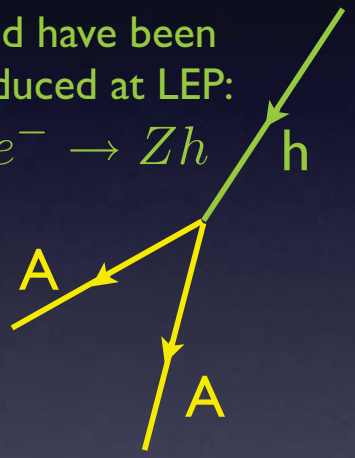
R.D., arXiv:0807.2135 [hep-ph]



If the light CP-odd Higgs is doublet like:

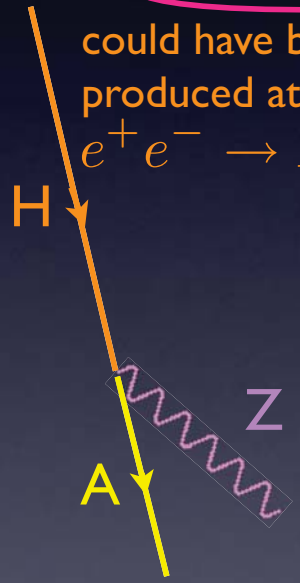
- all the Higgses (from two Higgs doublets) would be fairly light
- all the Higgses: h, H, $H^{\pm}$ would decay through the CP odd Higgs: A

could have been produced at LEP:
$e^+e^- \to Zh$

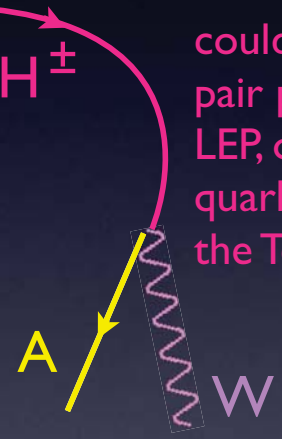


ongoing search at L3, studies and searches for Tevatron and LHC

could have been produced at LEP:
$e^+e^- \to HA$



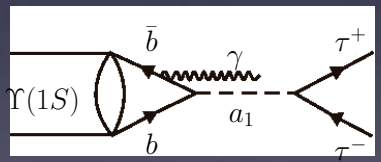
no searches or studies



no searches

could have been pair produced at LEP, or in top quark decays at the Tevatron

could have been produced at B factories



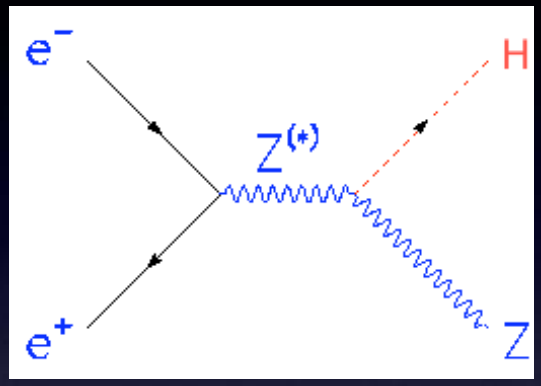
R.D., J. F. Gunion and B. McElrath, hep-ph/0612031
ongoing searches at B factories

- the extra singlet is not necessary

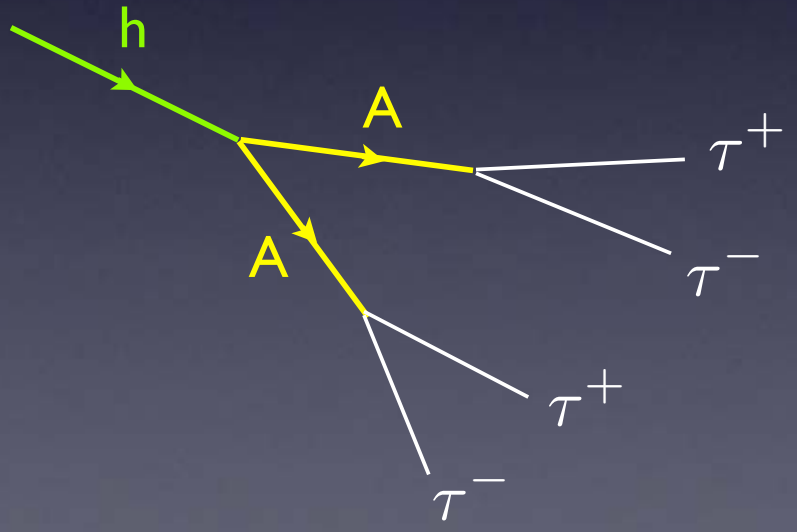
the scenario can be viable in many other models!

$h \to aa \to 4\tau$ at LEP:

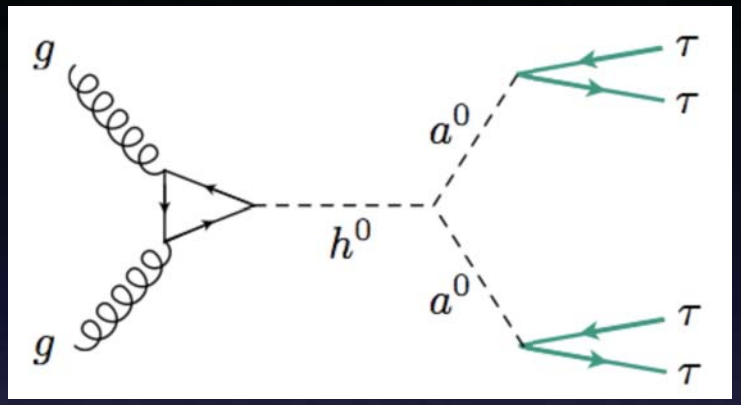
C. Tully, L3



$e^+e^- \to Zh$



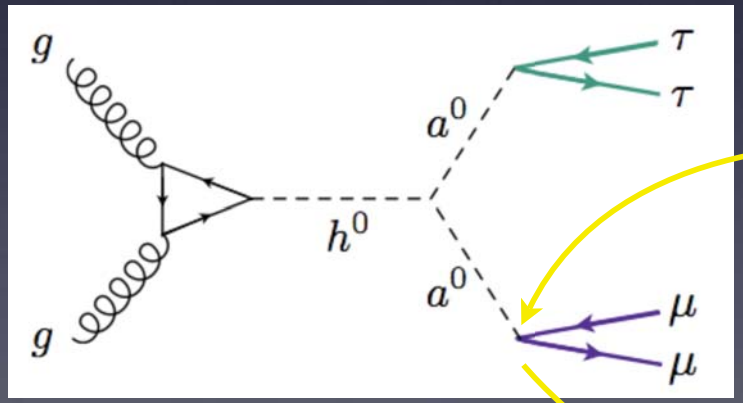
$h \to aa \to 4\tau$ at Tevatron and LHC:



$$h^0 \to 4\tau \to \text{ leptons} + \not{E}_T$$

M. Lisanti and J. Wacker, arXiv:0903.1377 [hep-ph]

M. Lisanti, Pheno 09



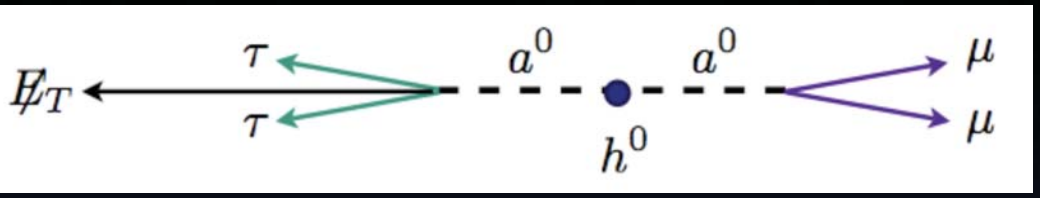
$$\frac{\Gamma(a^0 \to \mu^+\mu^-)}{\Gamma(a^0 \to \tau^+\tau^-)} = \frac{m_\mu^2}{m_\tau^2\sqrt{1-(2m_\tau/m_{a^0})^2}}$$

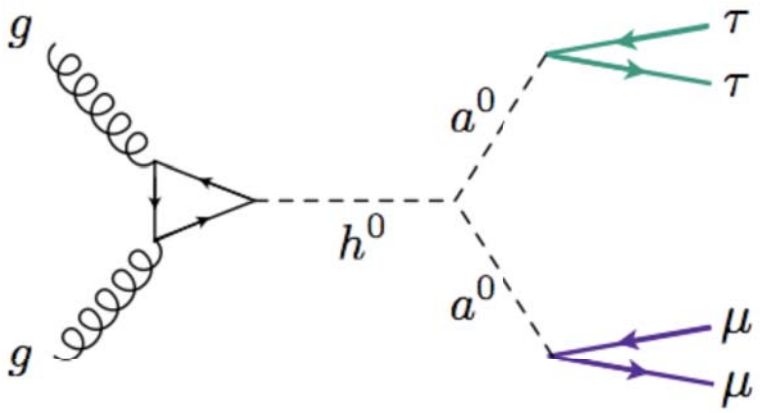
smaller but cleaner!

$$pp \to \mu^+\mu^- + \mathrm{di}\tau + \not{E}_T$$

M. Lisanti and J. Wacker, arXiv:0903.1377 [hep-ph]

M. Lisanti, Pheno 09





Branching fraction of a^0 to muons is much smaller than that to taus

$$\frac{\Gamma(a^0 \to \mu^+\mu^-)}{\Gamma(a^0 \to \tau^+\tau^-)} = \frac{m_\mu^2}{m_\tau^2\sqrt{1-(2m_\tau/m_{a^0})^2}}$$

For 7 GeV pseudoscalar,

$$\mathrm{Br}(a^0 \to \mu^+\mu^-) = 0.4\%$$

$$\mathrm{Br}(a^0 \to \tau^+\tau^-) = 98\%$$

Despite small branching fraction to muons...

300 events 20 fb^{-1} Tevatron

250 events 0.5 fb^{-1} LHC

DØ-search for $h \rightarrow 2\mu 2\tau$

DØ, arXiv:0905.3381 [hep-ex] (PRL)

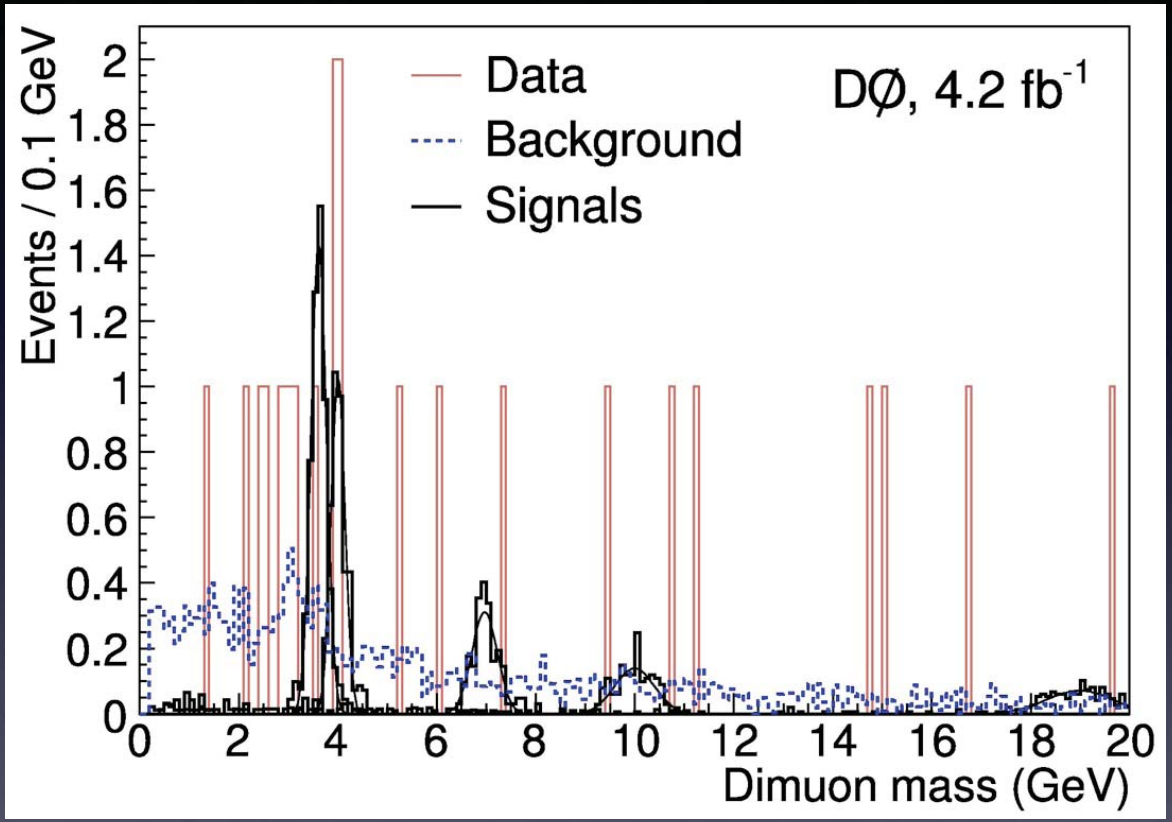
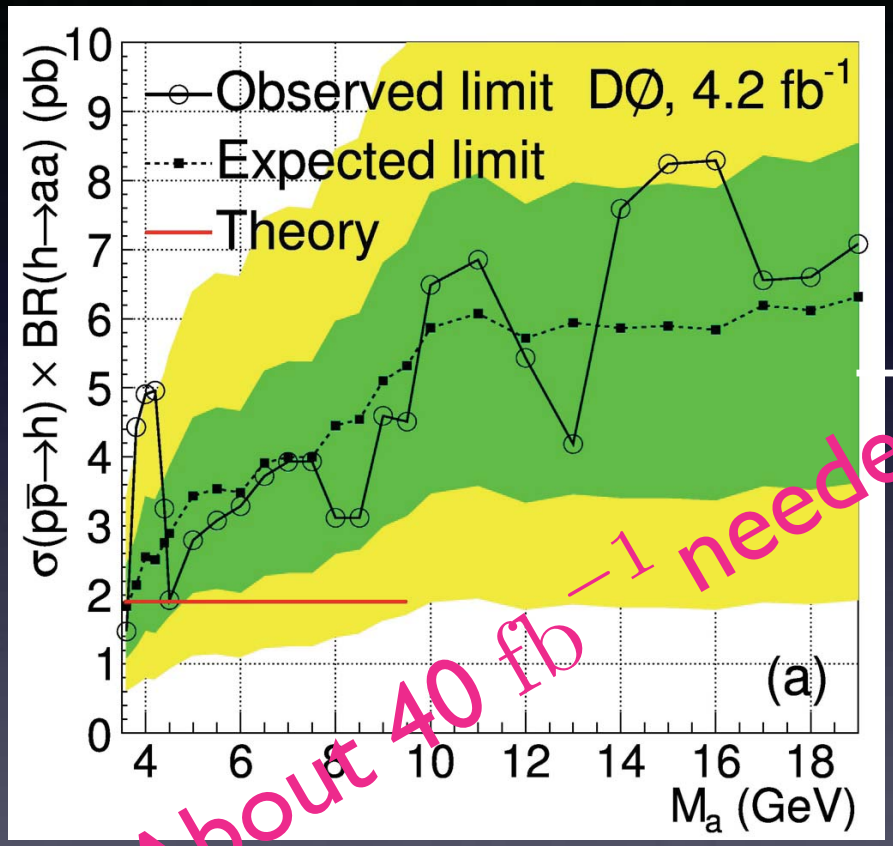
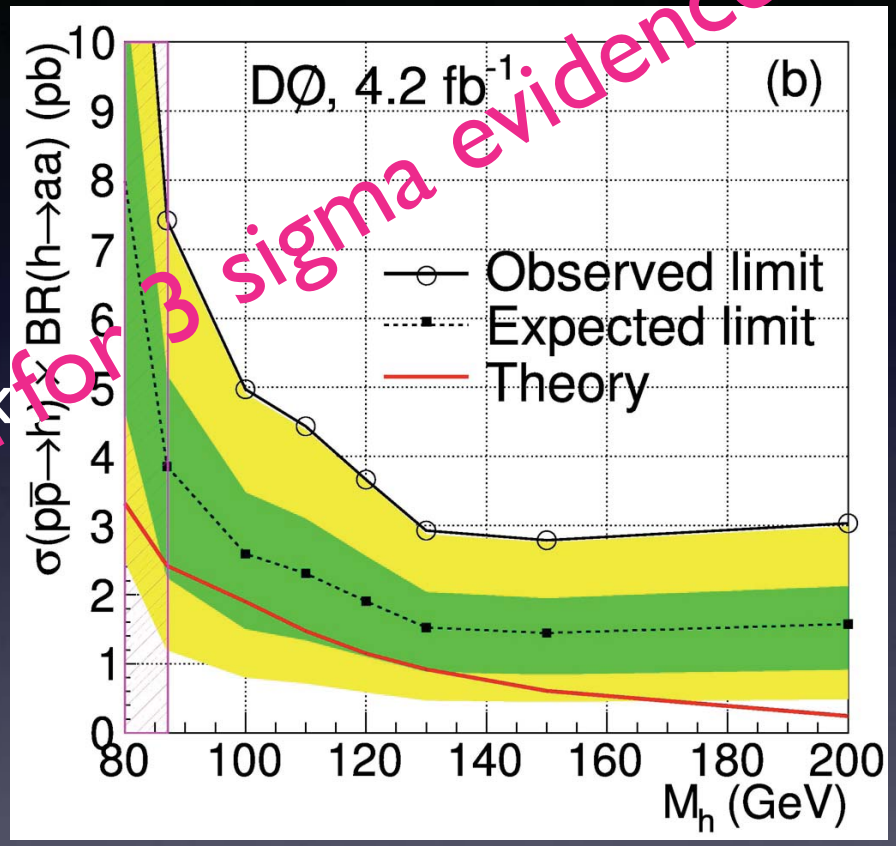


FIG. 2: The dimuon invariant mass for events passing all selections in data, background, and $2\mu 2\tau$ signals for M_a = 3.6, 4, 7, 10, and 19 GeV. $\sigma(p\bar{p} \rightarrow h+X)$=1.9 pb is assumed, BR($h \rightarrow aa$)=1, and M_h=100 GeV.

DØ-search for $h \to 2\mu 2\tau$

DØ, arXiv:0905.3381 [hep-ex] (PRL)



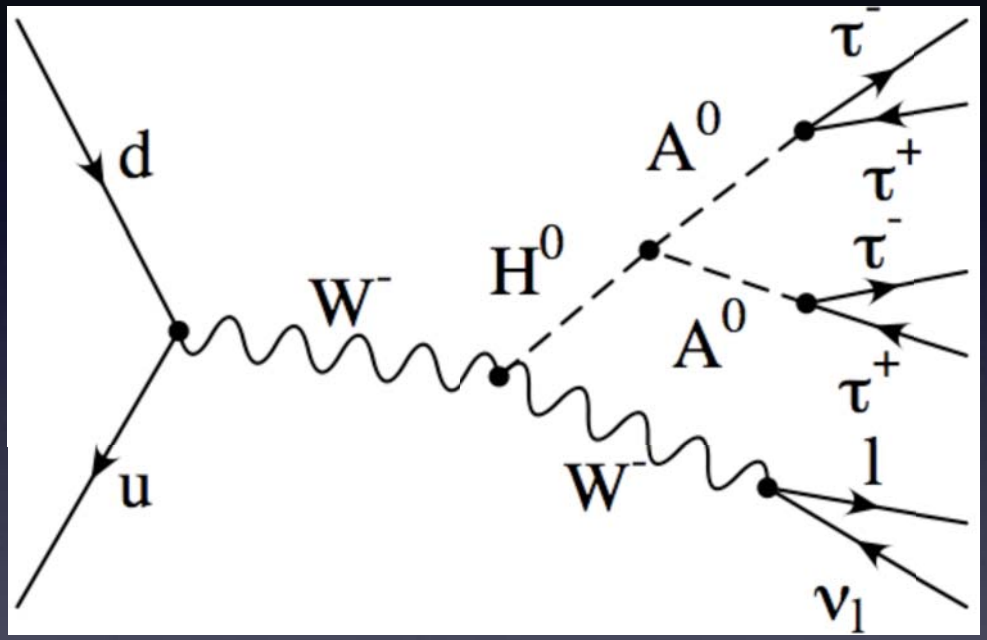


About 40 fb^{-1} needed for 3 sigma evidence!

FIG. 3: The expected and observed limits and ±1 s.d. and ±2 s.d. expected limit bands for $\sigma(p\bar{p}\to h+X)\times \mathrm{BR}(h\to aa)$, for (a) M_h=100 GeV and (b) M_a=4 GeV. The signal for $\mathrm{BR}(h\to aa)$=1 is shown by the solid line. The region M_h<86 GeV is excluded by LEP.

CDF-search for $h \longrightarrow aa \longrightarrow 4\tau$

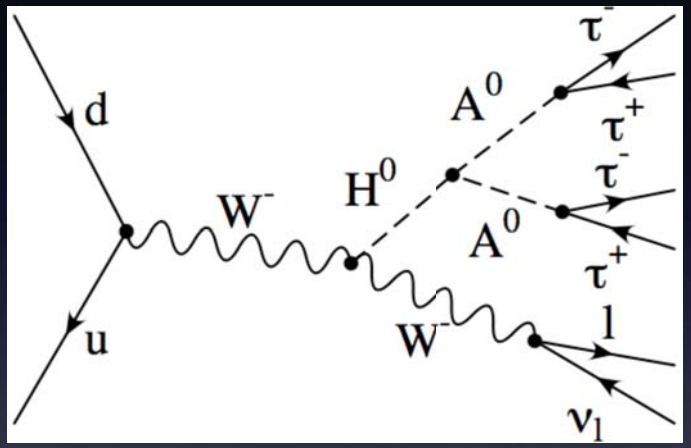
S. Wilbur, CDF, Pheno 09

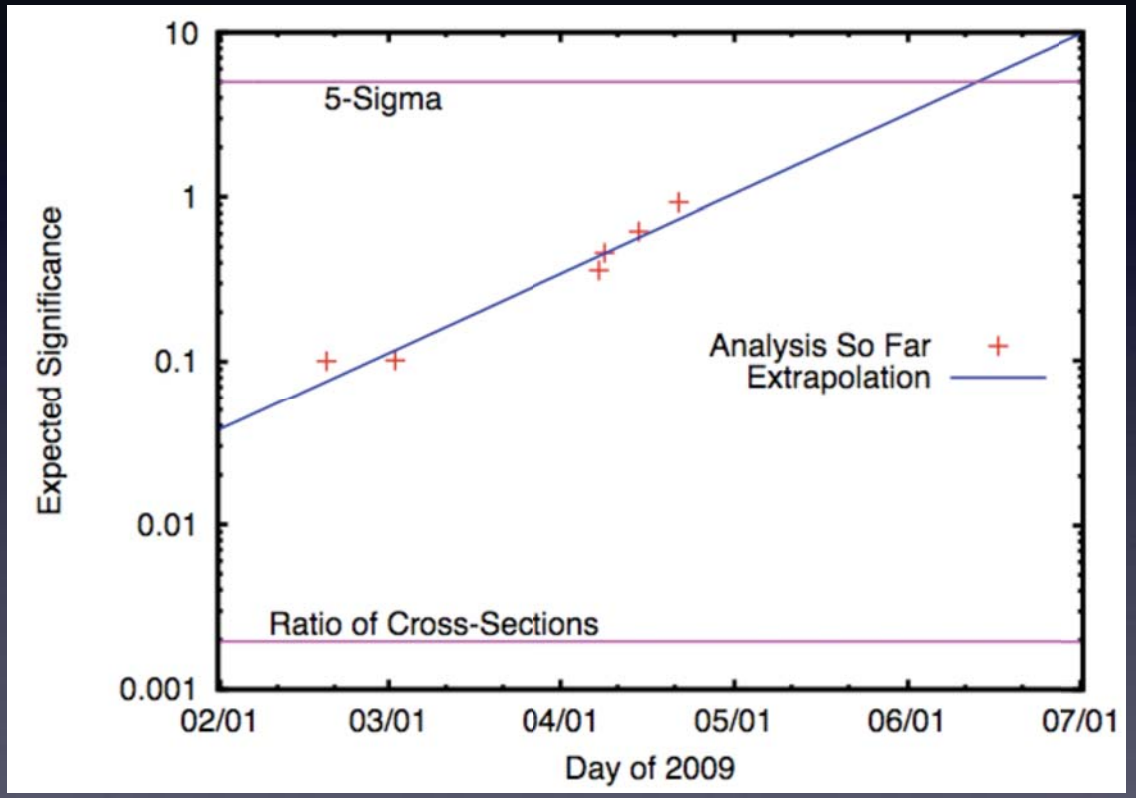


the goal is to
identify di-tau objects

CDF-search for $h \longrightarrow aa \longrightarrow 4\tau$

S. Wilbur, CDF, Pheno 09





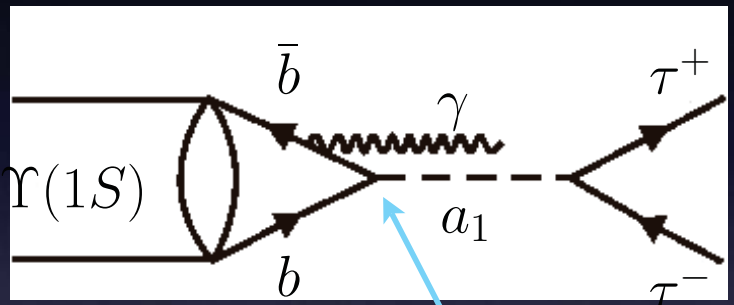
plan is to reach 5-sigma sensitivity this summer! :)

Light CP-odd Higgs at B factories

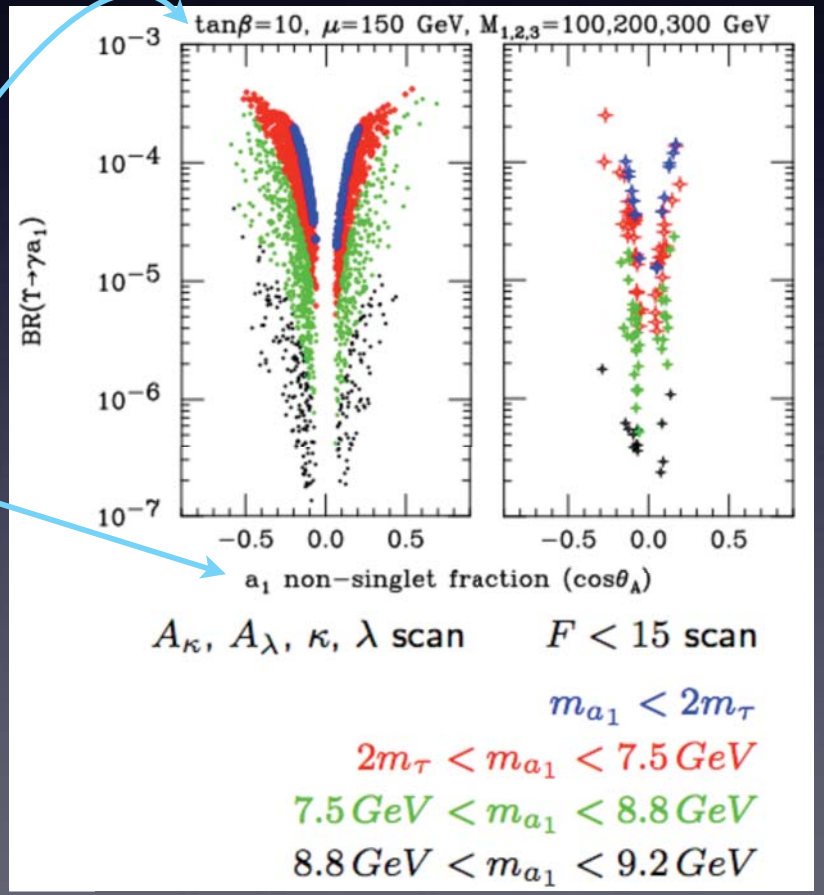
R.D., J. Gunion and B. McElrath, hep-ph/0612031

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

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



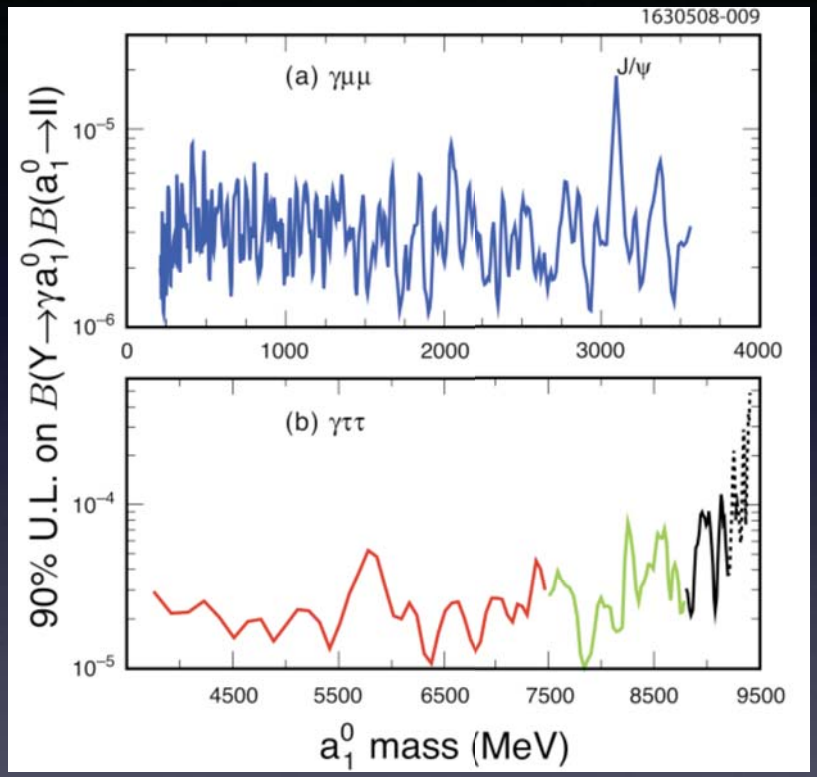
$$C_{a_1 b\bar{b}} = \cos\theta_A \tan\beta$$

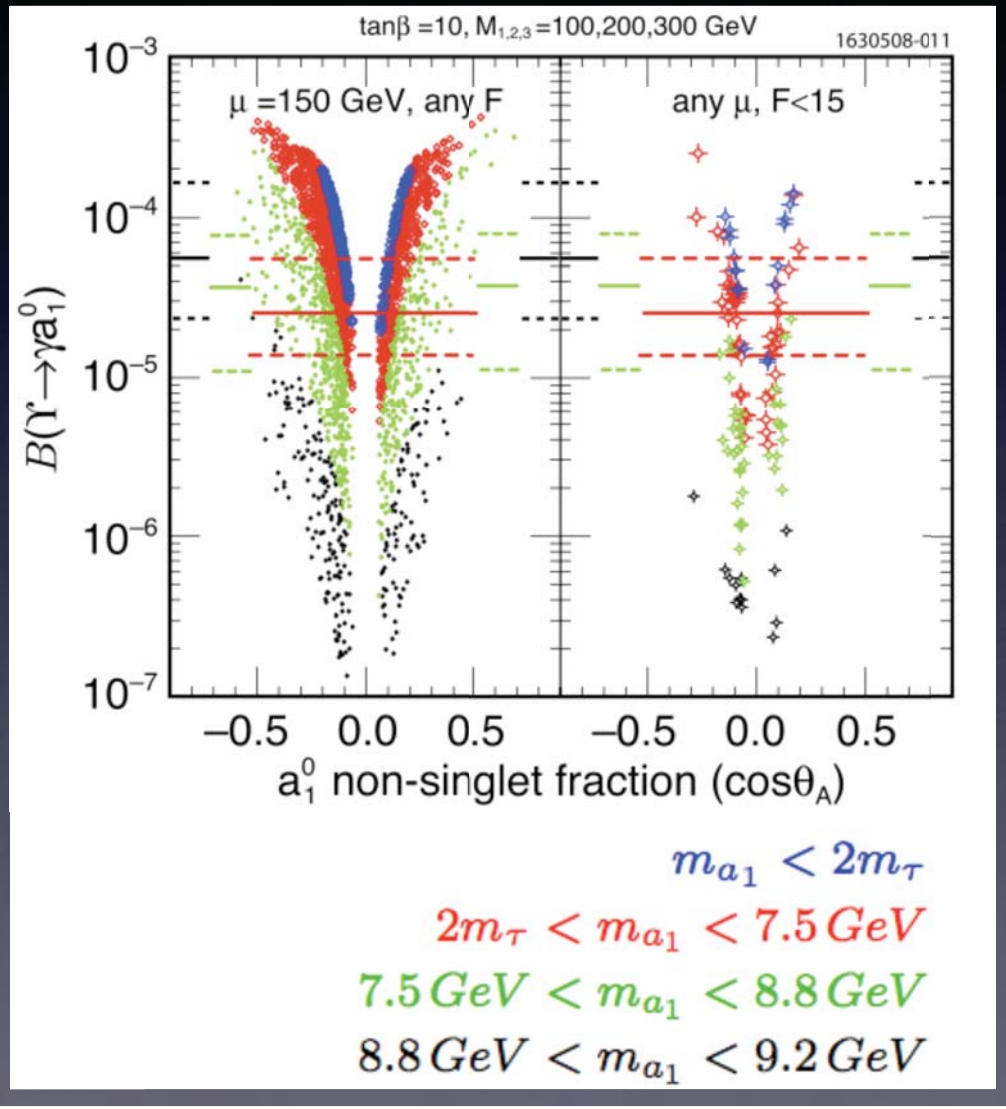


Within the reach at existing facilities!

CLEO limits on the light CP-odd Higgs

CLEO, arXiv:0807.1427 [hep-ex]



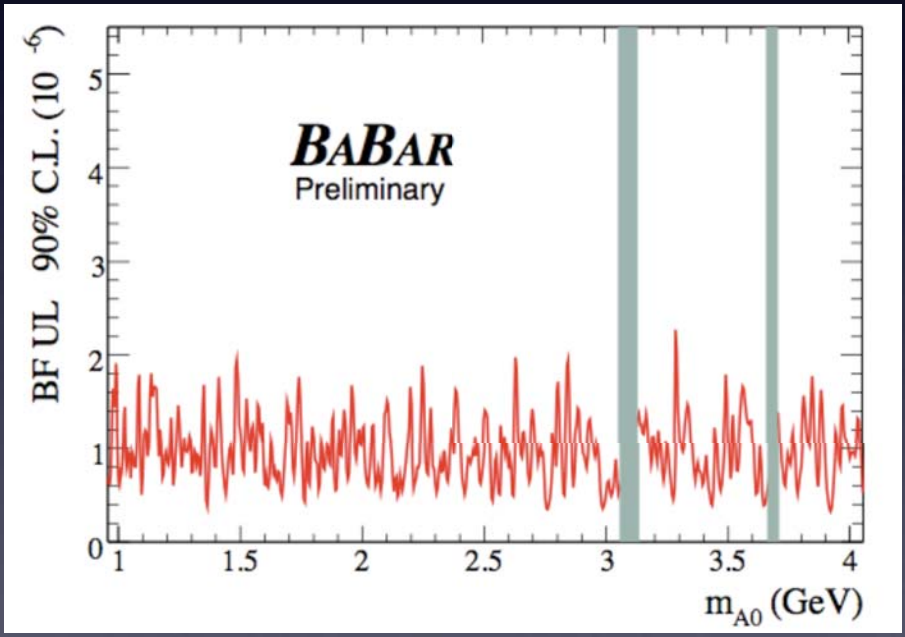


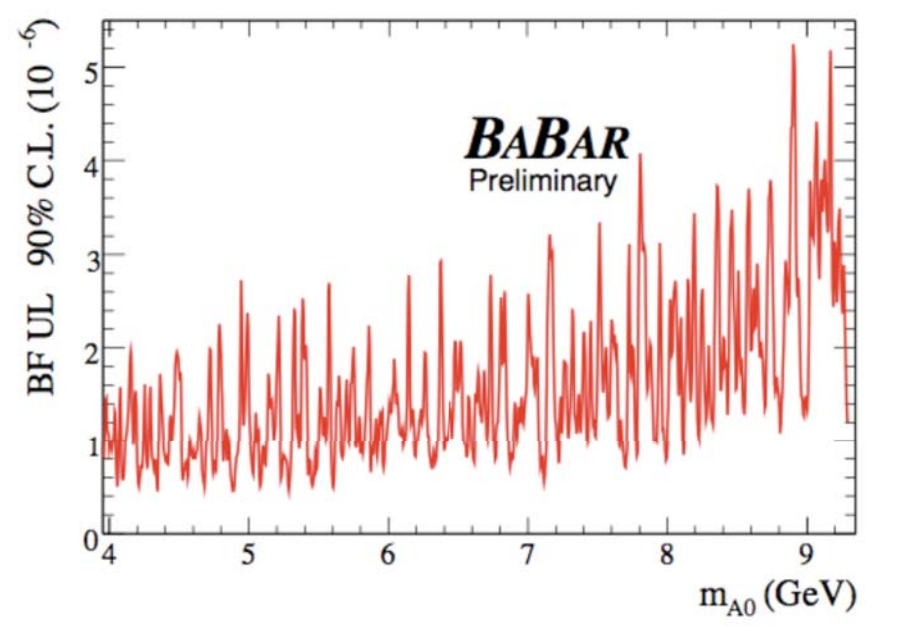
21.5 mil. of $\Upsilon(1S)$

BaBar limits on the light CP-odd Higgs

BaBar, arXiv:0902.2176 [hep-ex]

$$\mathcal{B}(\Upsilon(3S) \to \gamma A^0) \times \mathcal{B}(A^0 \to \mu^+\mu^-)$$



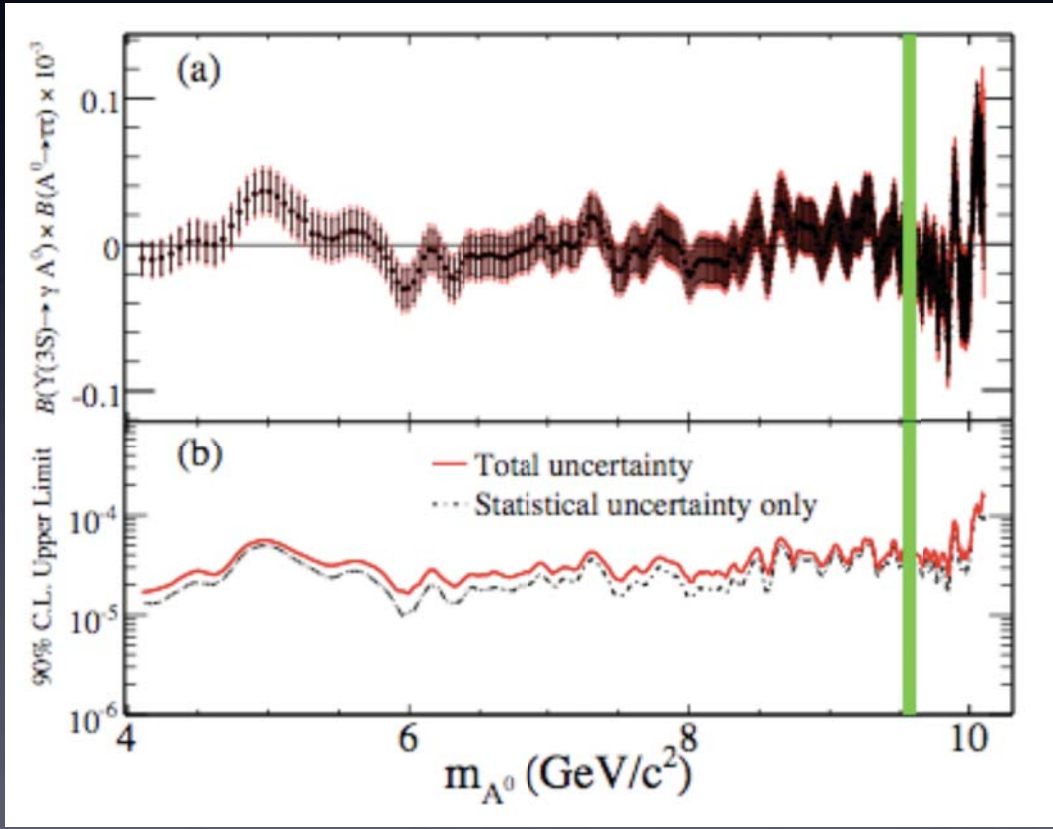


Not stronger than CLEO

BaBar limits on the light CP-odd Higgs

BaBar, arXiv:0906.2219 [hep-ex]

$$\mathcal{B}(\Upsilon(3S) \to \gamma A^0) \times \mathcal{B}(A^0 \to \tau^+\tau^-)$$

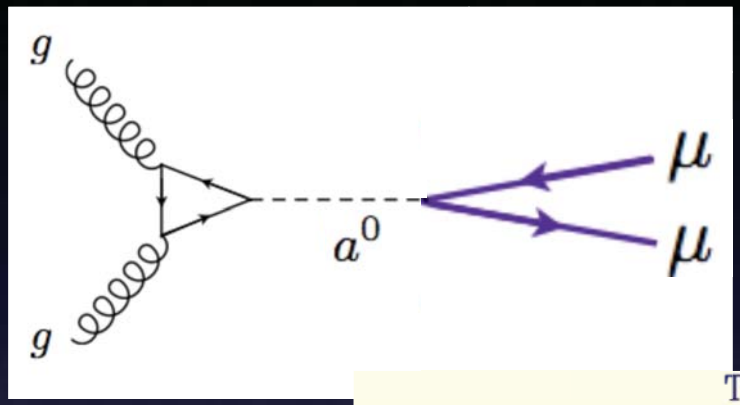


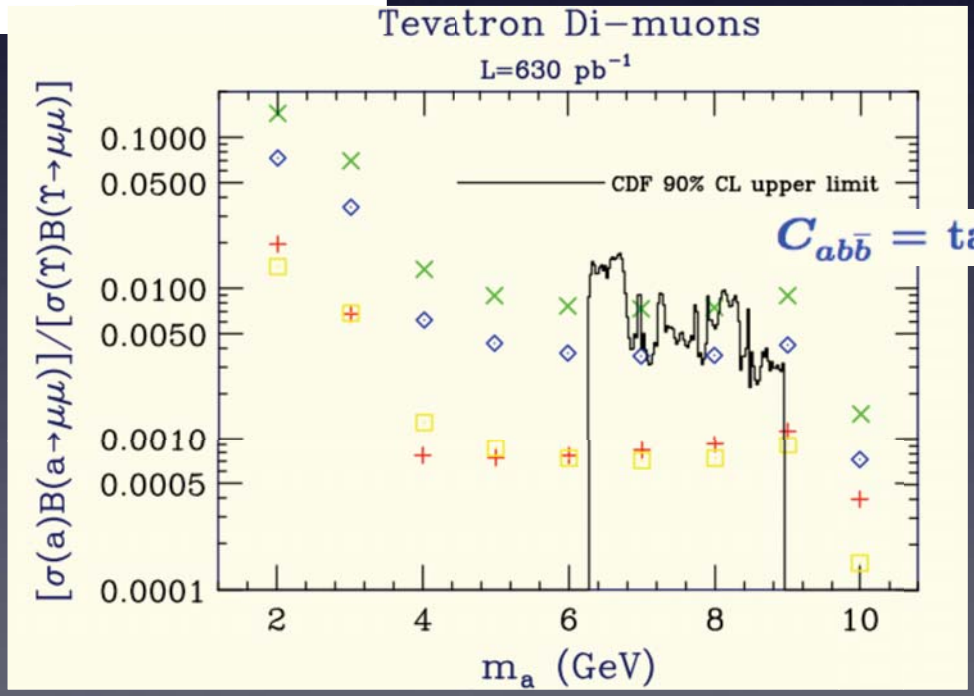
122 mil. of $\Upsilon(3S)$

comparable to CLEO

Light CP-odd Higgs at Tevaron (and LHC)

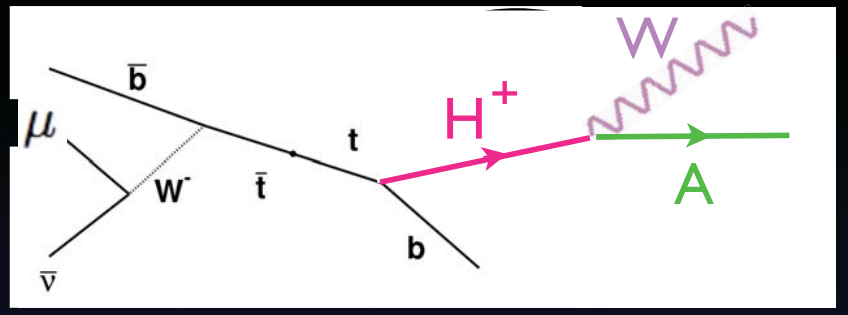
R.D. and J. Gunion, in progress

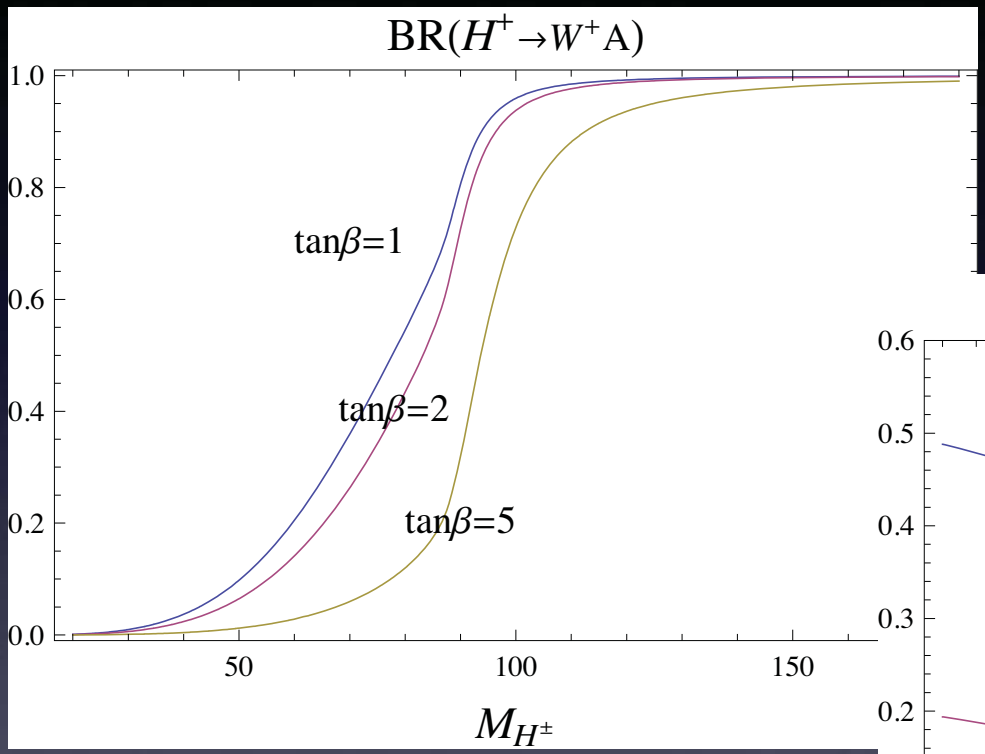


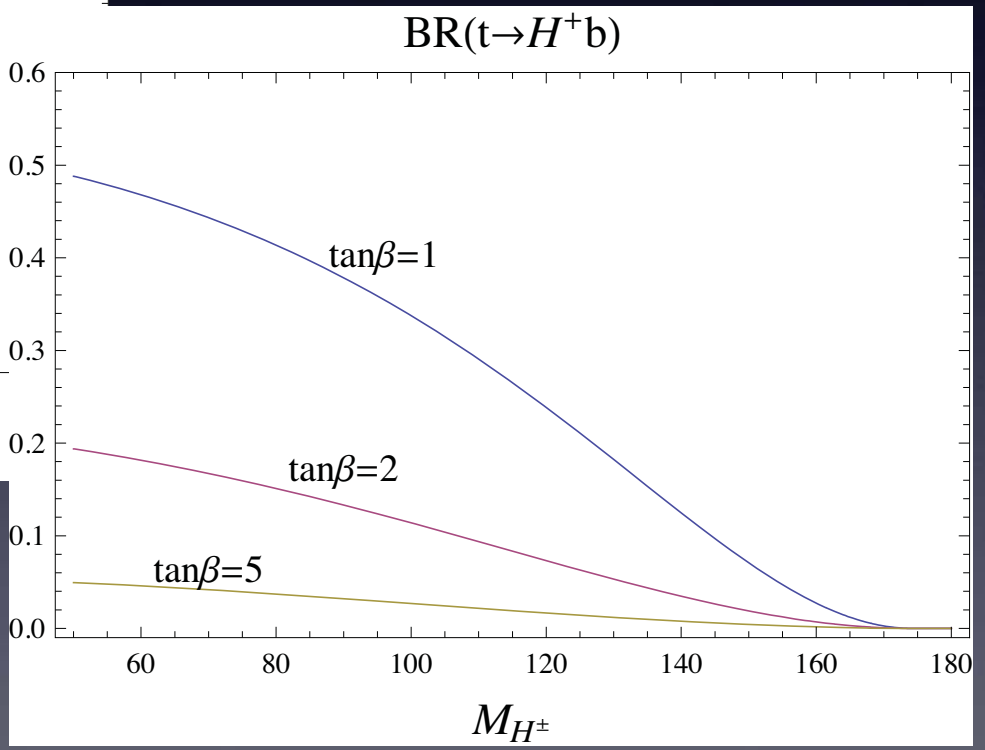


$C_{ab\bar{b}} = \tan\beta \cos\theta_A = 1,\ 2,\ 3$

Charged Higgs:

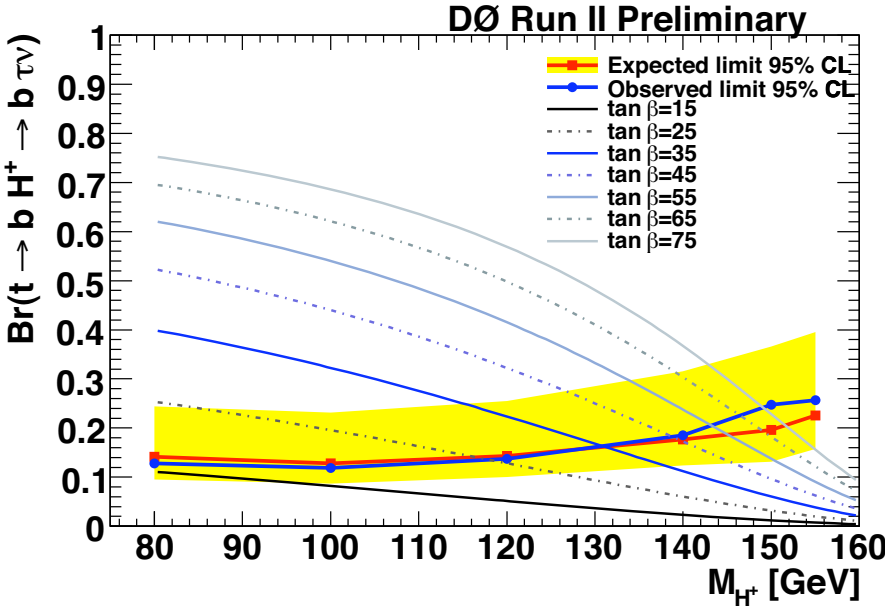


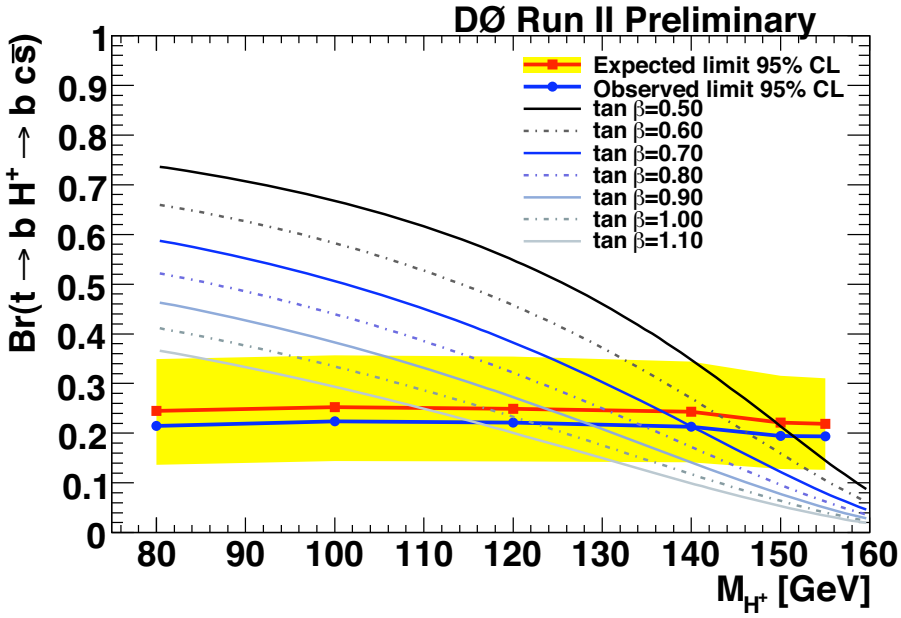




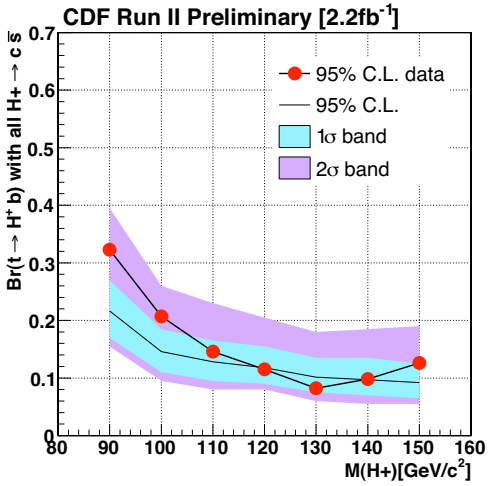
New D0 and CDF limits on charged Higgs

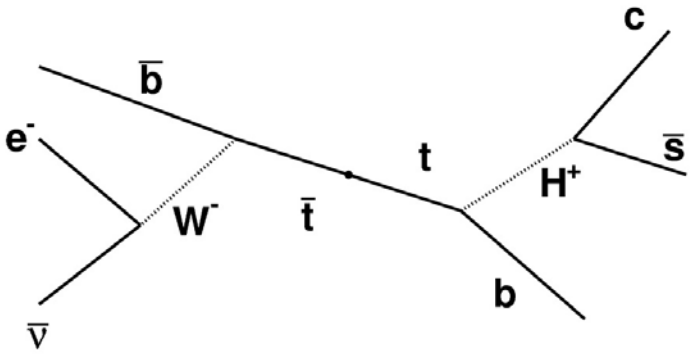
Aug 08





limits do not constrain our scenario!



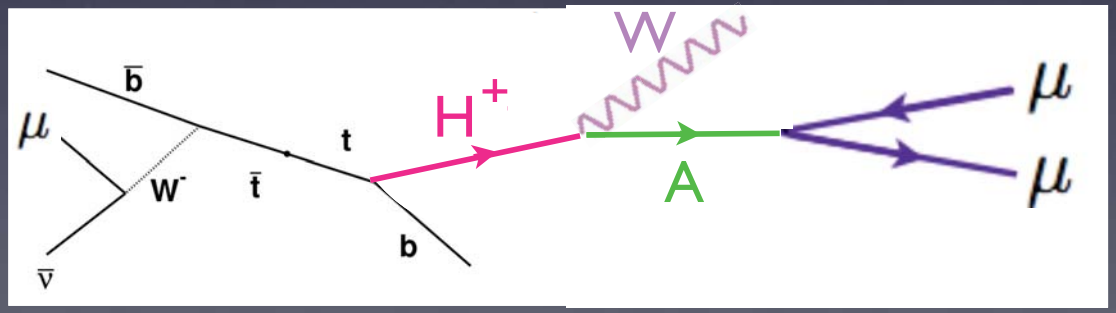


Charged Higgs at the LHC

R.D. and E. Lunghi, in progress

LHC is a top factory: 4 000 000 top pairs at 10 TeV with 10 fb^{-1}

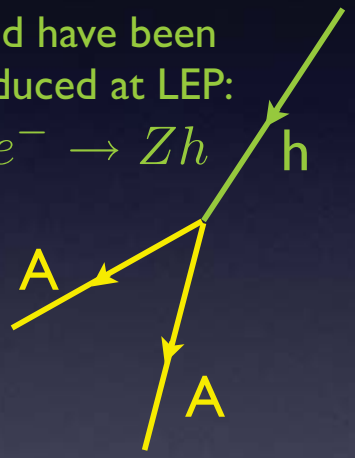
- one of the two Ws: $W \to \mu\nu$ 20%
- CP-odd Higgs: $a \to \mu\mu$ 1/250
- for $Br(t \to H^+ b) = 10\%$ we have 650 3-muon events



Consequences of a light doublet-like CP-odd Higgs:

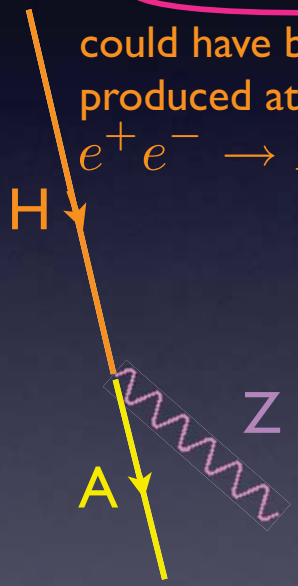
- all the Higgses (from two Higgs doublets) would be fairly light
- all the Higgses: h, H, $H^{\pm}$ would decay through the CP odd Higgs: A

could have been produced at LEP:
$e^+e^- \to Zh$

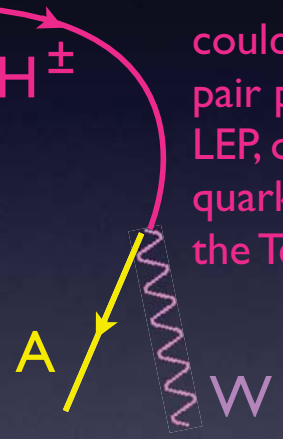


ongoing search at L3, studies and searches for Tevatron and LHC

could have been produced at LEP:
$e^+e^- \to HA$



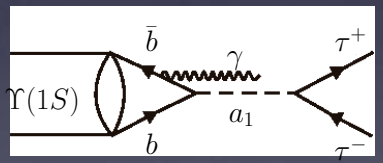
no searches or studies



could have been pair produced at LEP, or in top quark decays at the Tevatron

no searches

could have been produced at B factories



ongoing searches at B factories

- the extra singlet is not necessary

the scenario can be viable in many other models!