Hidden Higgs Scenarios

new constraints and prospects at the LHC

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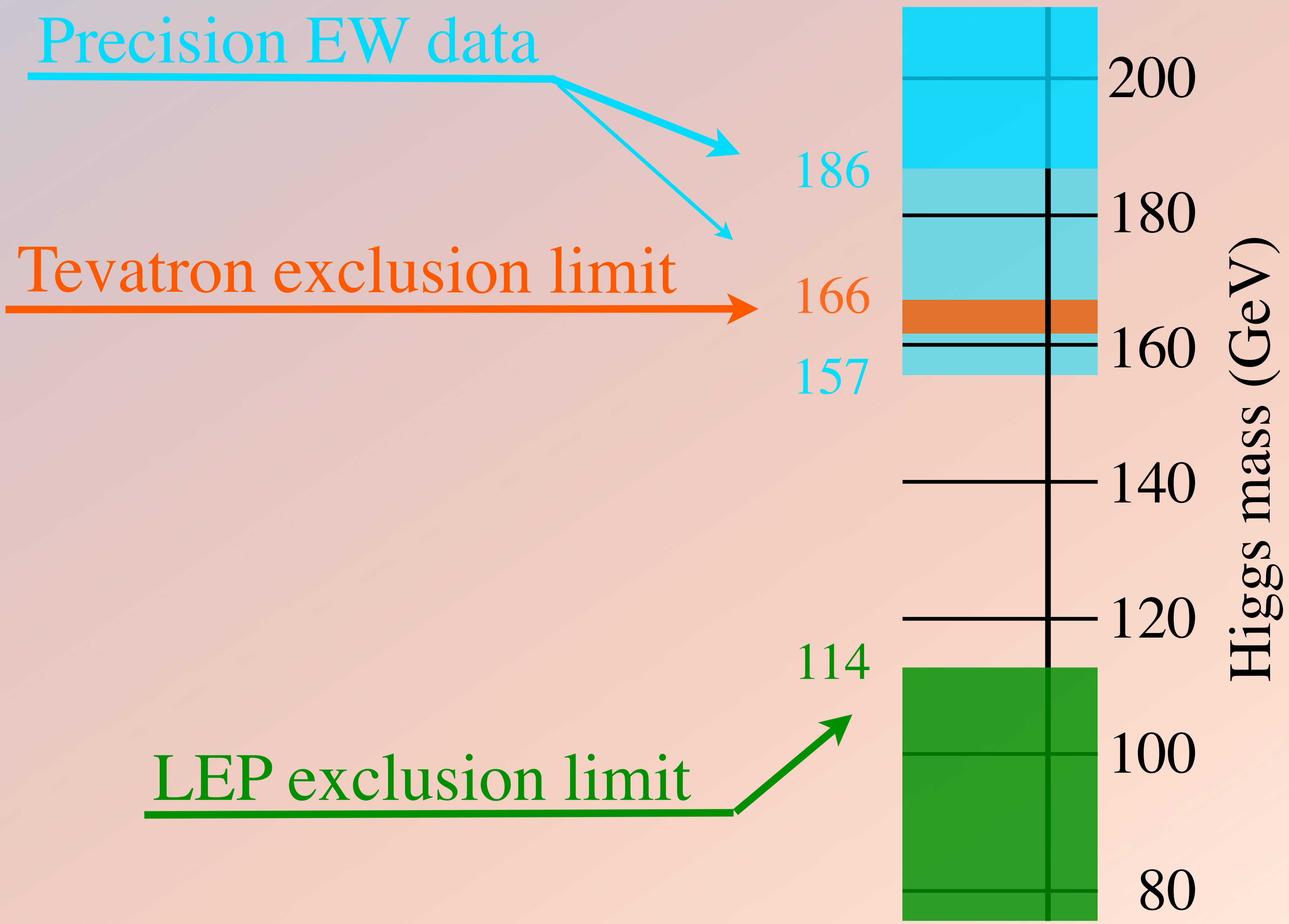
Indiana University, Bloomington

Physics at the LHC 2010, DESY, June 7-12, 2010

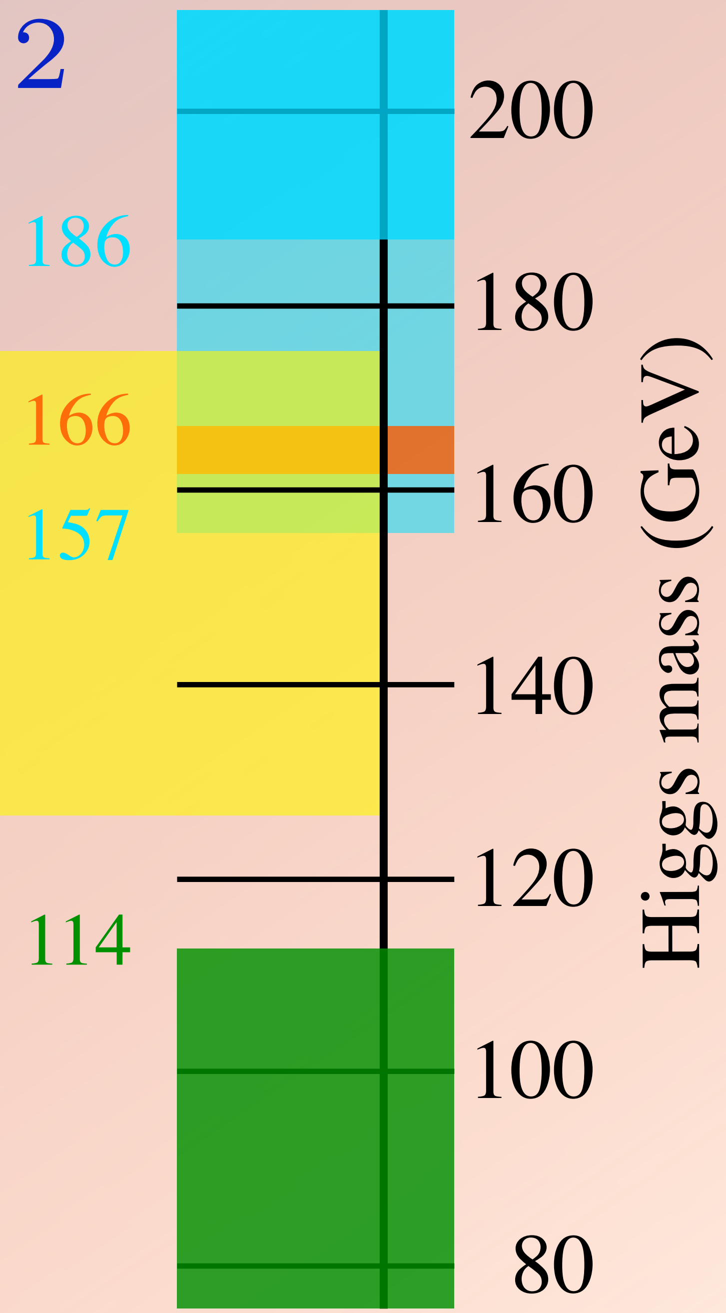
Where is the Higgs?



Interesting coincidences

$$V_{higgs} = -m^2\phi^\dagger\phi + \lambda\left(\phi^\dagger\phi\right)^2$$

In this range the standard model can be a consistent theory all the way to the grand unification scale!



lower limit: stability of the EW vacuum

upper limit: absence of a Landau pole

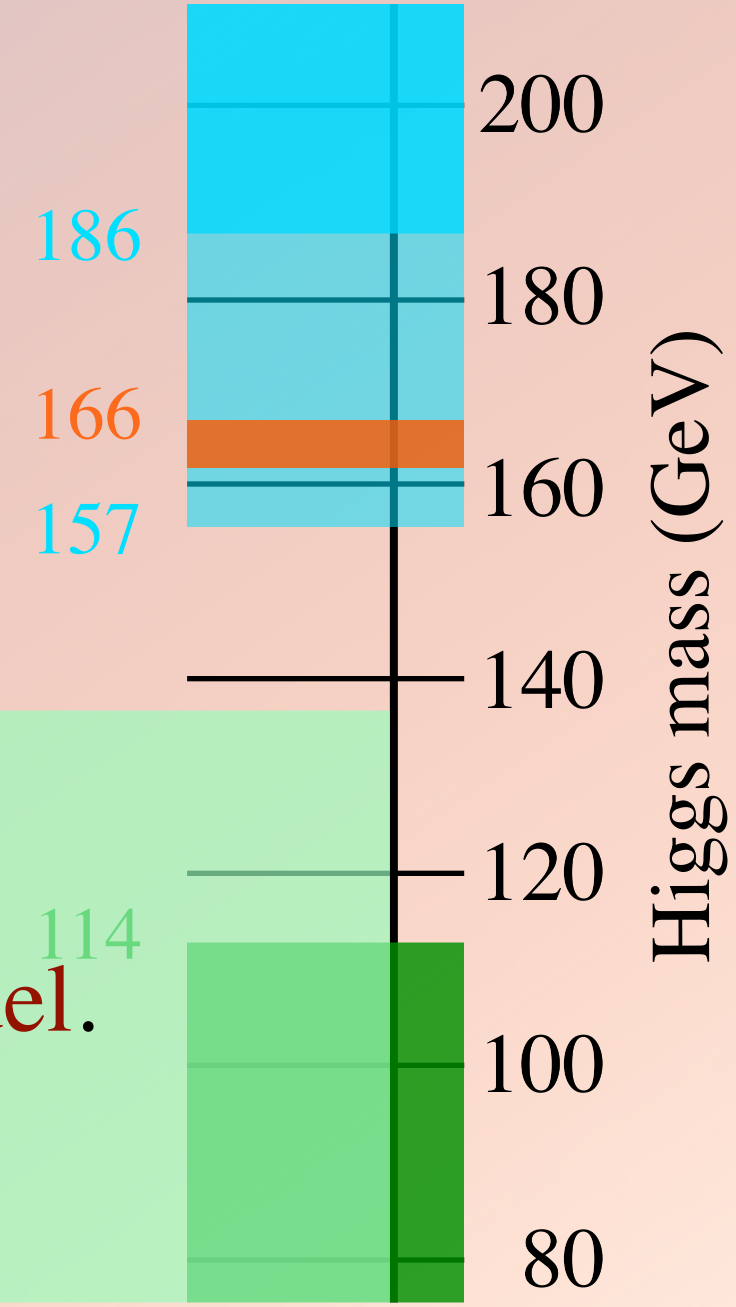
$$m_h^2 = 2\lambda v^2$$

Interesting coincidences

In the MSSM:

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + 1 - loop$$

This range corresponds to the Higgs mass predicted in the minimal supersymmetric model.



Interesting coincidences

In the MSSM:

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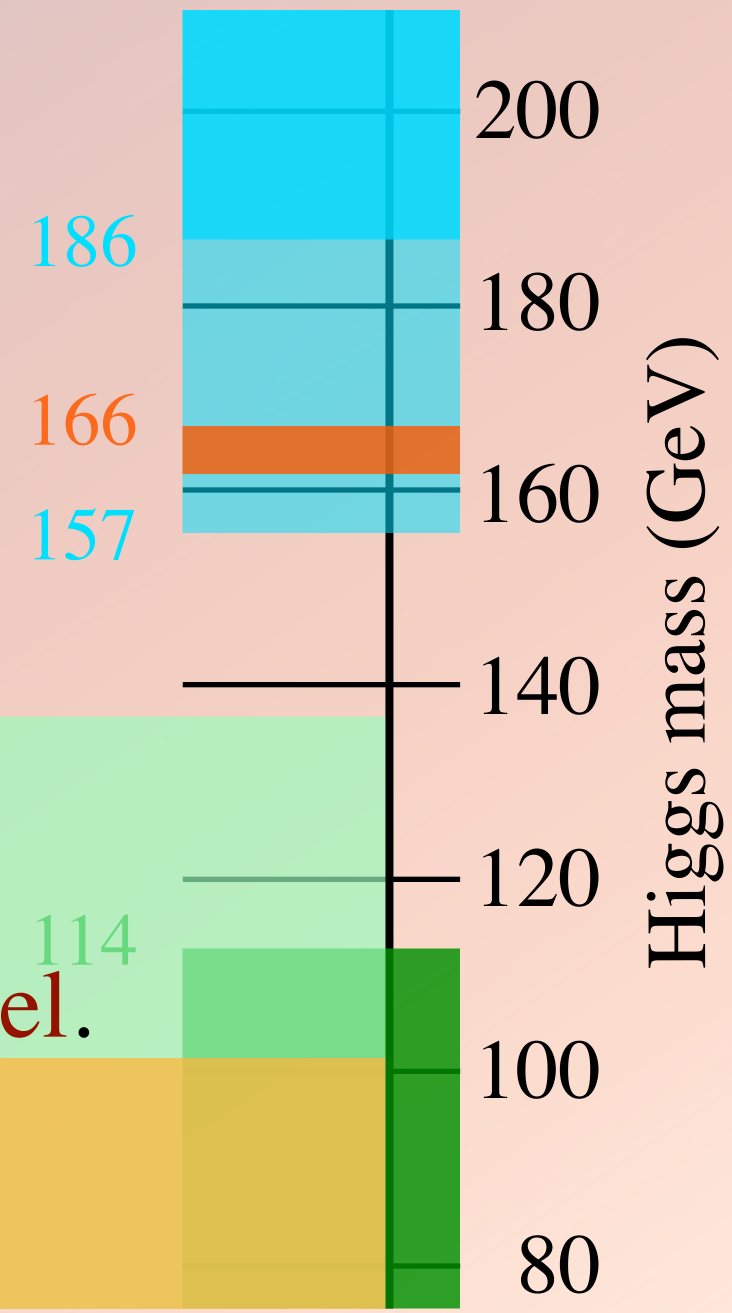
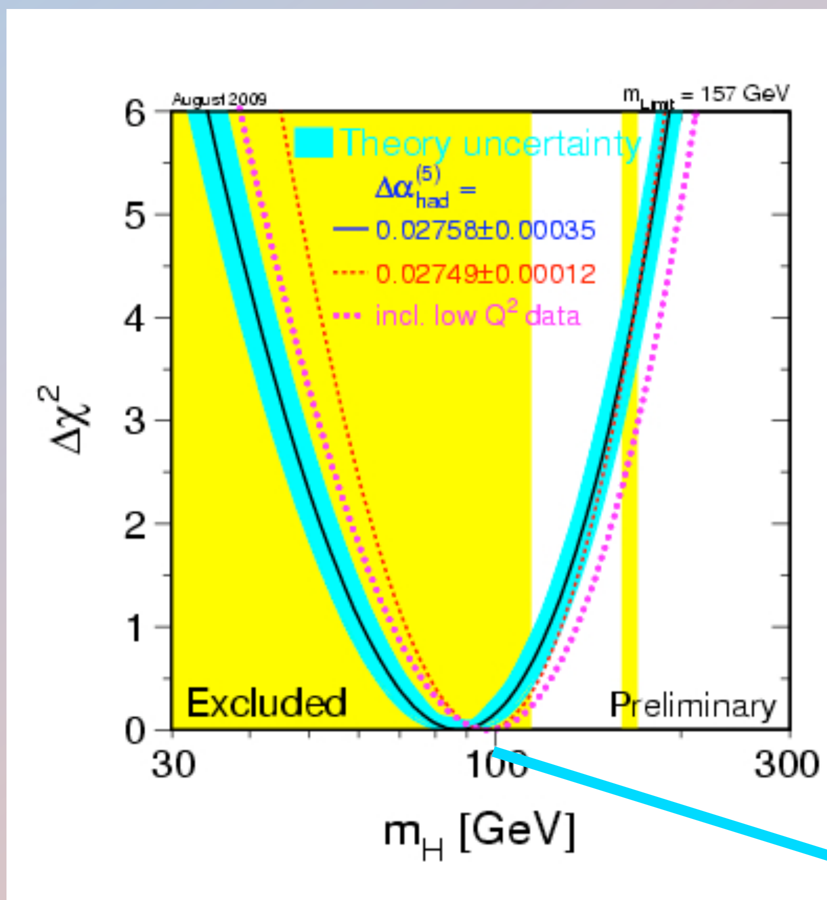
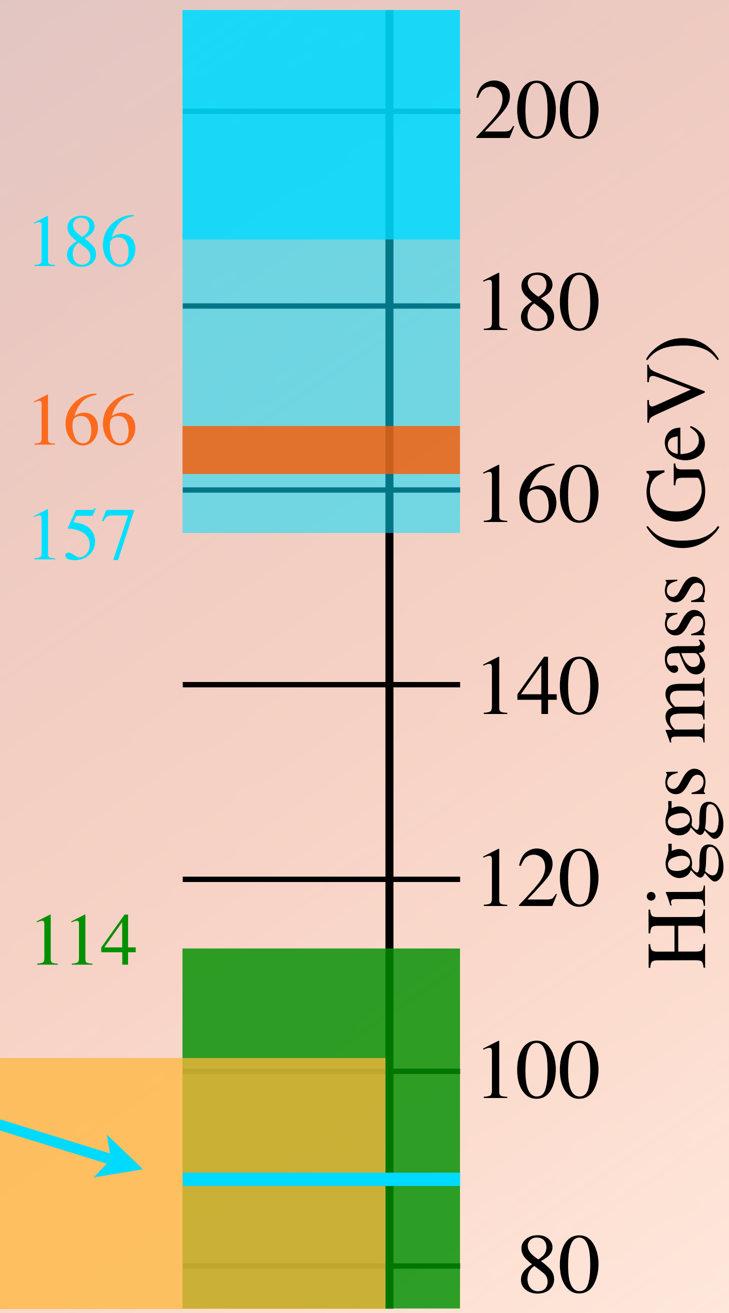
Natural electroweak symmetry breaking in SUSY models is achieved only in this region!



Interesting coincidences



the best fit value



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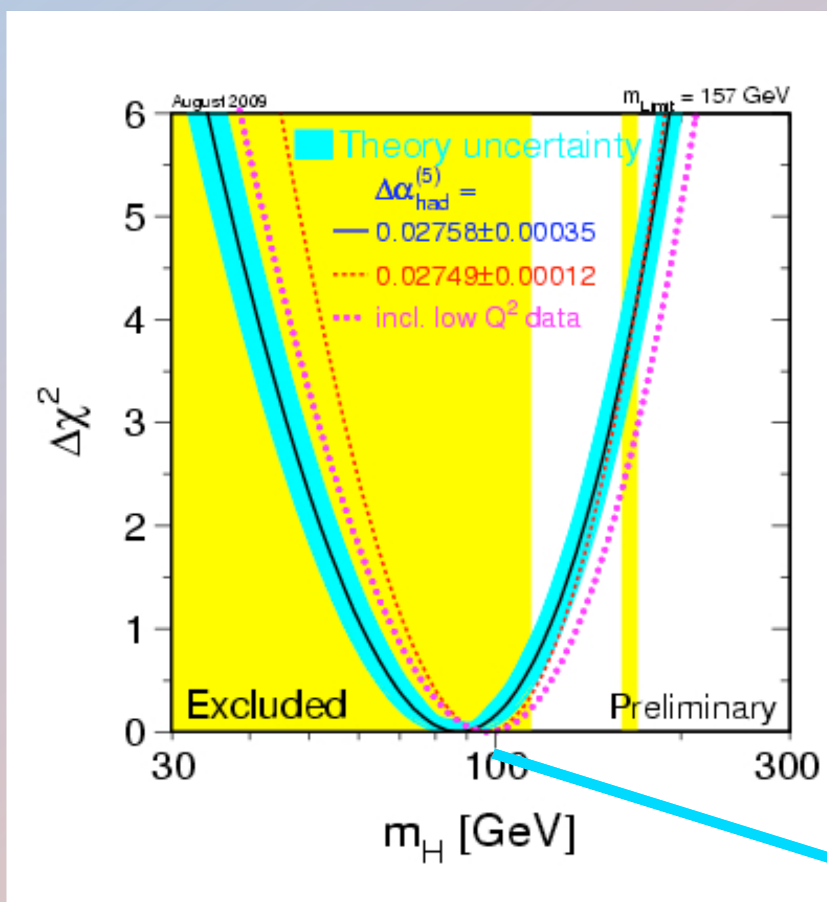
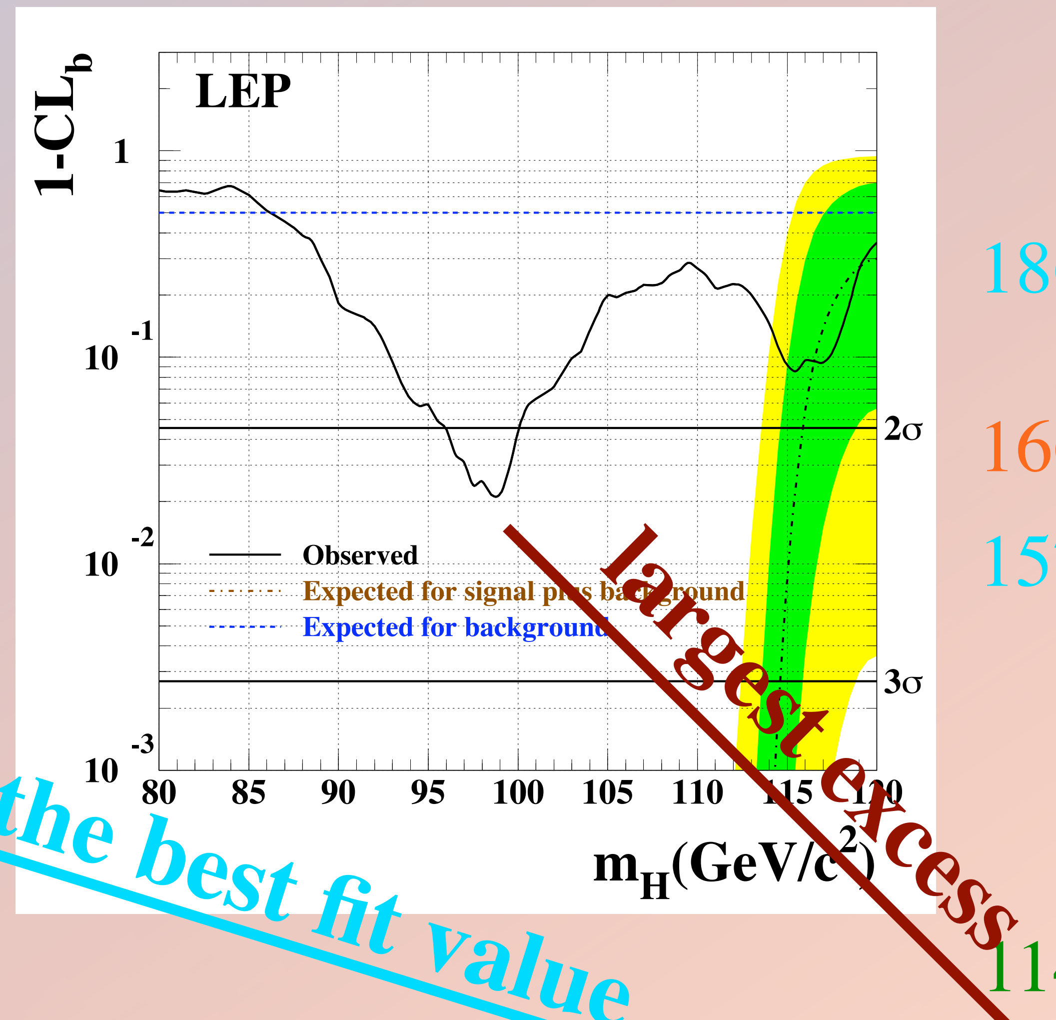
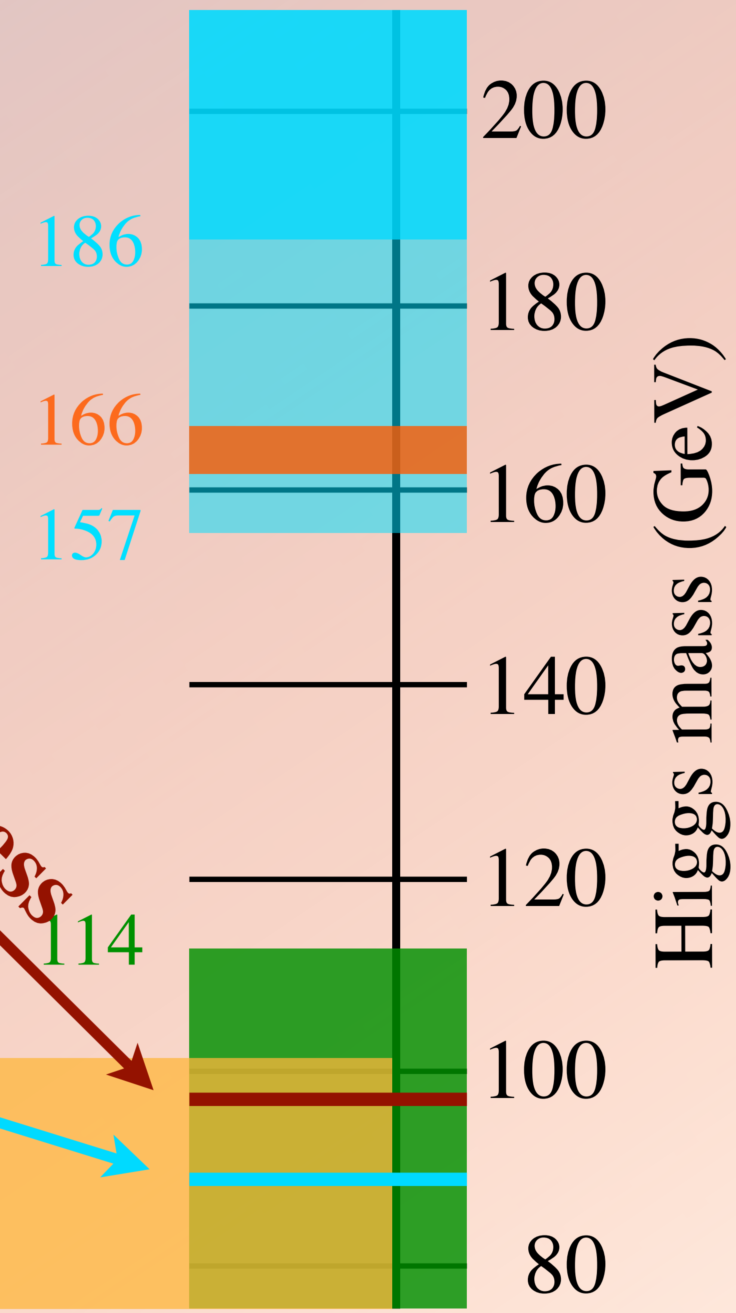
Interesting coincidences







Natural electroweak symmetry breaking in SUSY models is achieved only in this region!

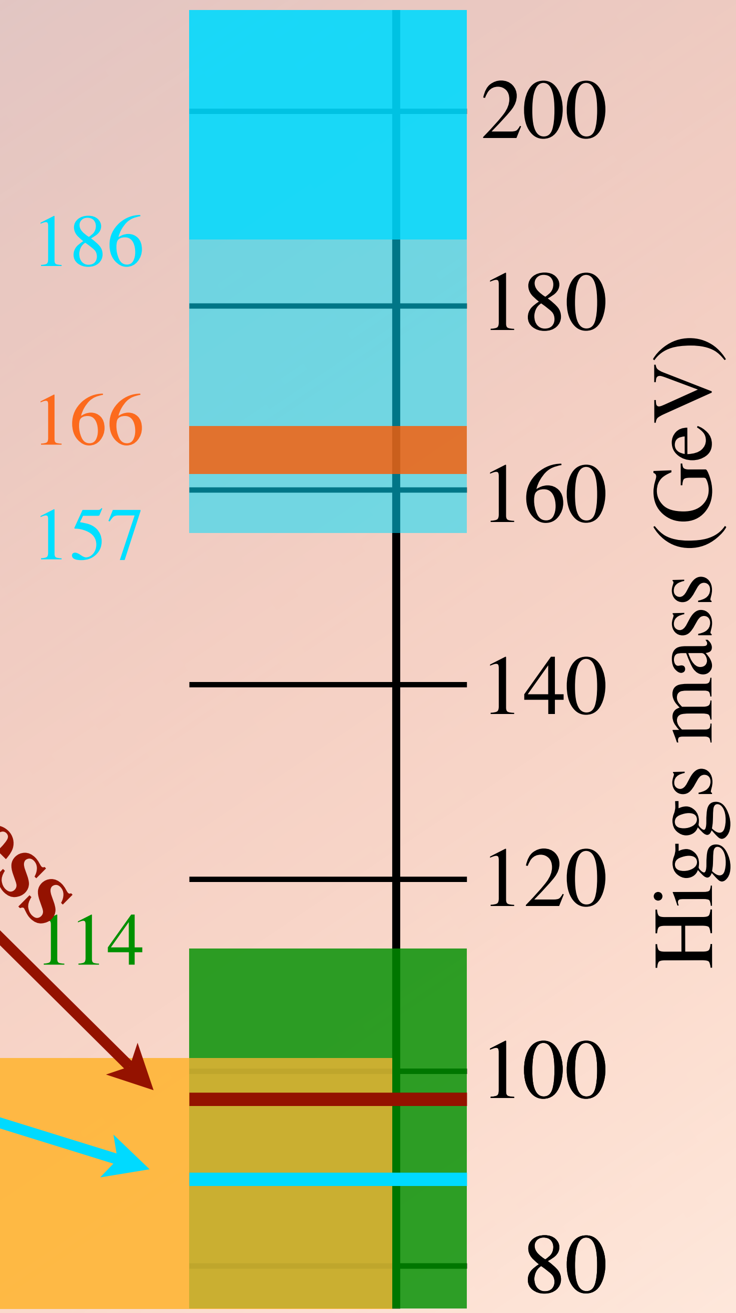
Non-standard Higgs decays

R.D. and J. Gunion, 2005

Basic idea: if the SM-like Higgs boson decays in a different way then the usual experimental limits do not apply. Such a Higgs can be light, as predicted from SUSY, gives better agreement with precision electroweak data and a can even explain the largest excess of Higgs like events at LEP.

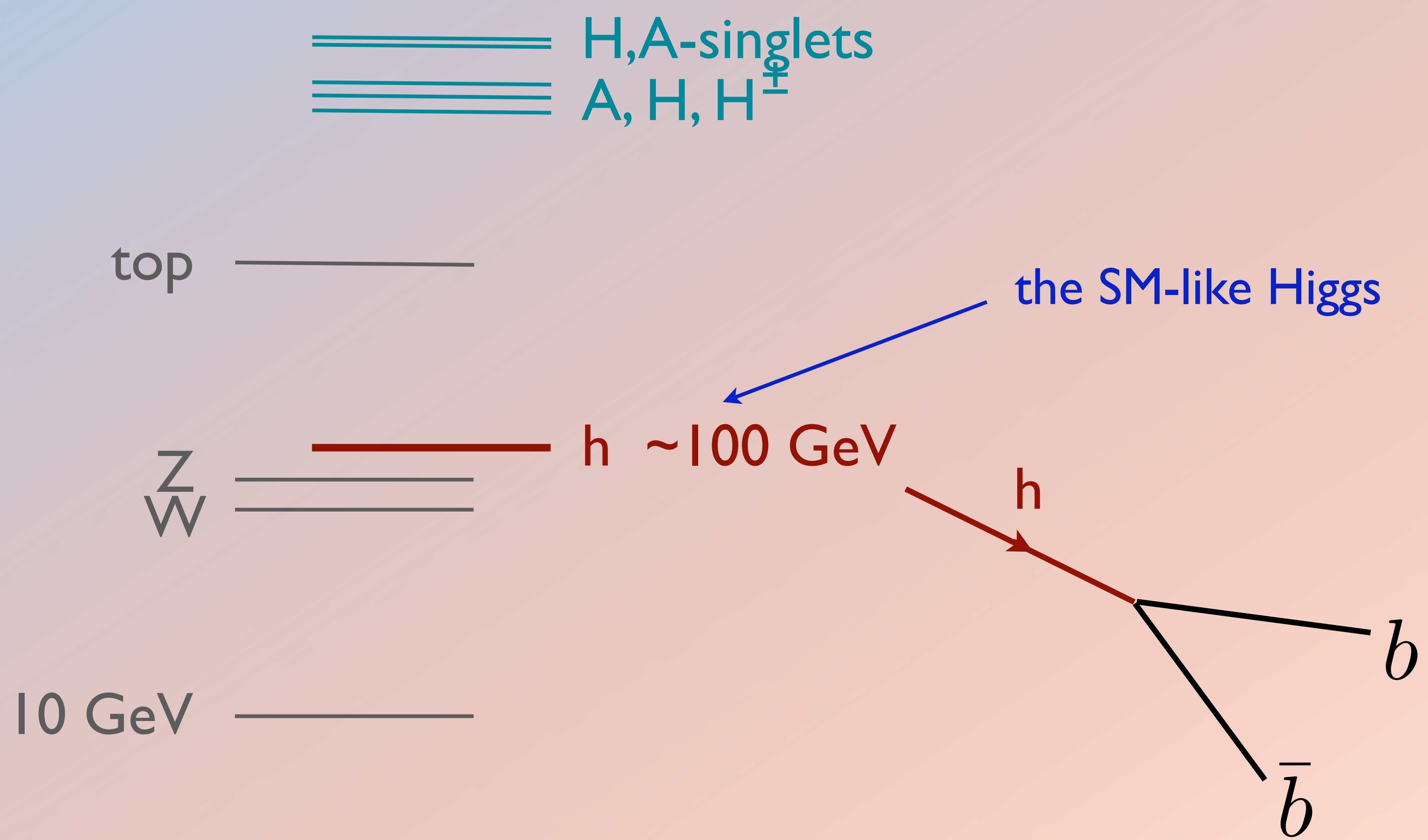
largest excess

the best fit value



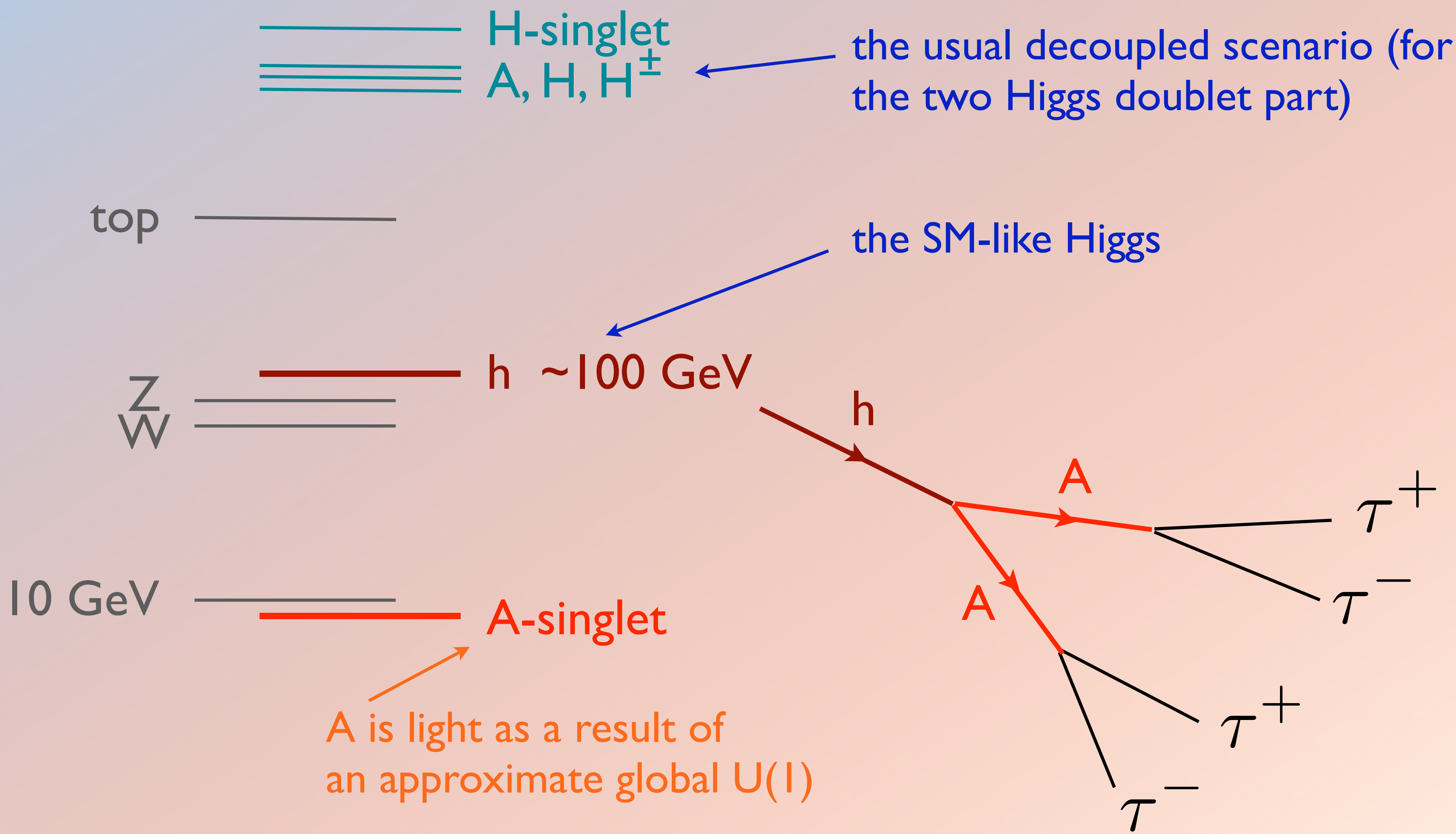
Natural electroweak symmetry breaking in SUSY models is achieved only in this region!

(N)MSSM - the usual story (decoupling)



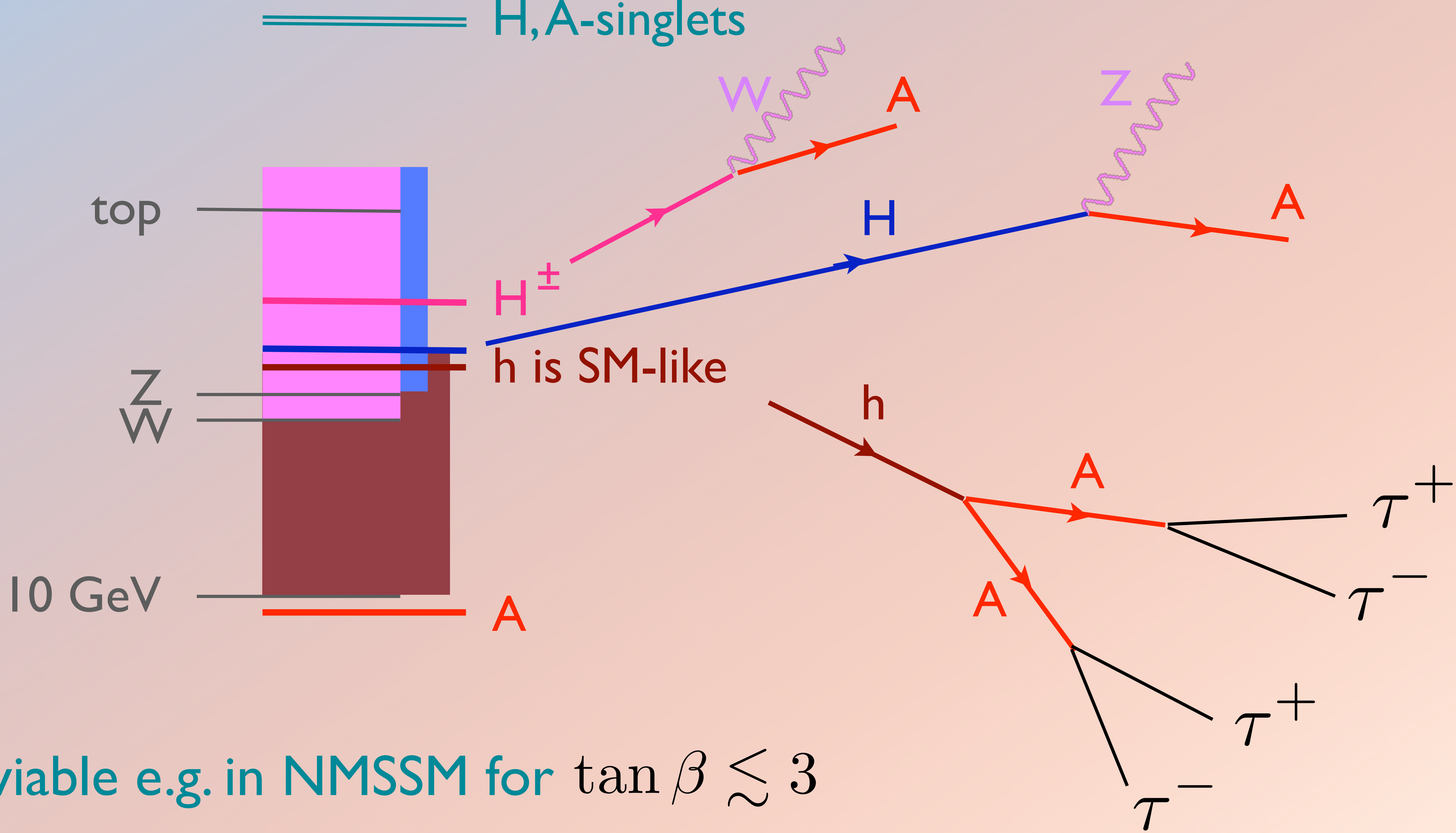
NMSSM with a light CP odd Higgs

R.D. and J. Gunion, 2005



Models with a light doublet-like A

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



viable e.g. in NMSSM for $\tan\beta \lesssim 3$

More complex Higgs decays

- $h \to aa \to 4\tau$, 4q, 4g - simplest possibilities allowing $m_h \simeq 100$ GeV
- more complex possibilities:

$$h \to 2\phi_2 \to 4\phi_1 \to 8f$$

$$h \to 2\phi_i \to 4\phi_j \to \cdots \to \text{ (large number of) } f$$

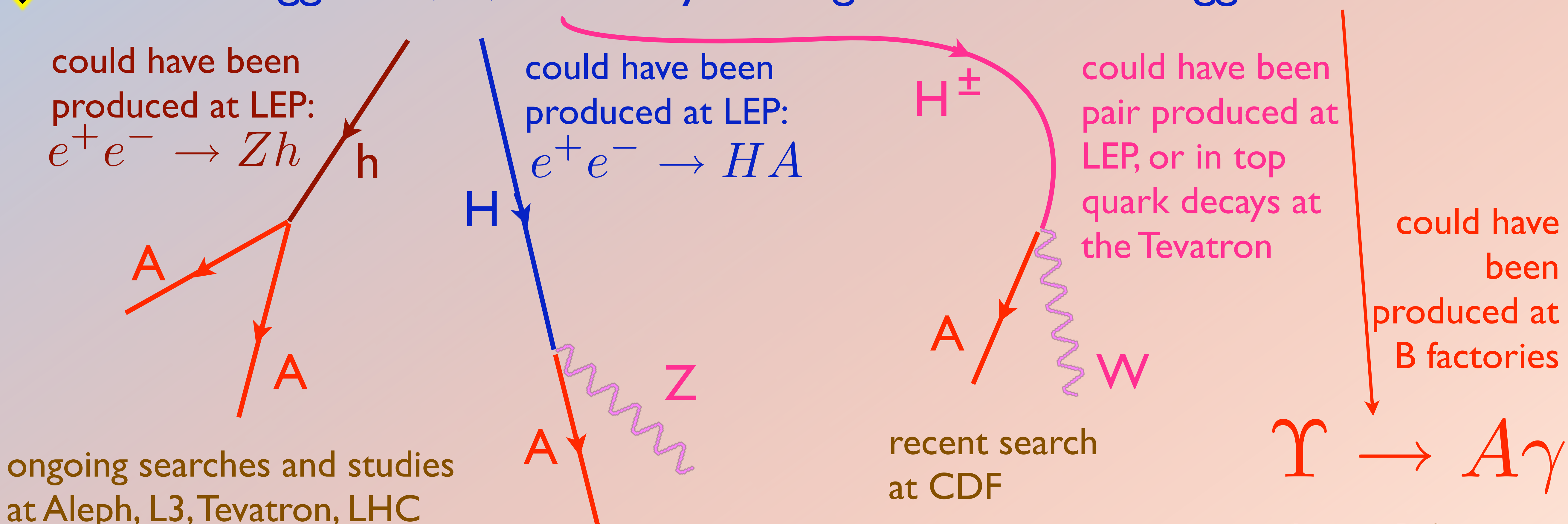
if the lightest scalar is lighter than $2m_e$:

$$h \to \text{ (large number of) } \gamma$$

jets of soft particles

Summary of the light doublet-like CP odd Higgs scenario

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



no searches or studies

searches at B factories
direct production at Tevatron and LHC

- the extra singlet is not necessary

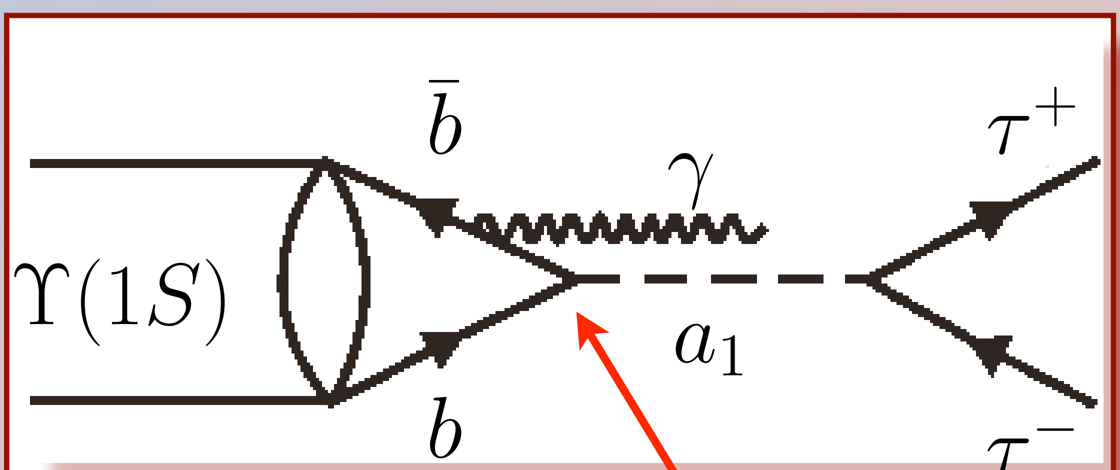
the scenario can be viable in many other models!

Light CP odd Higgs at B factories

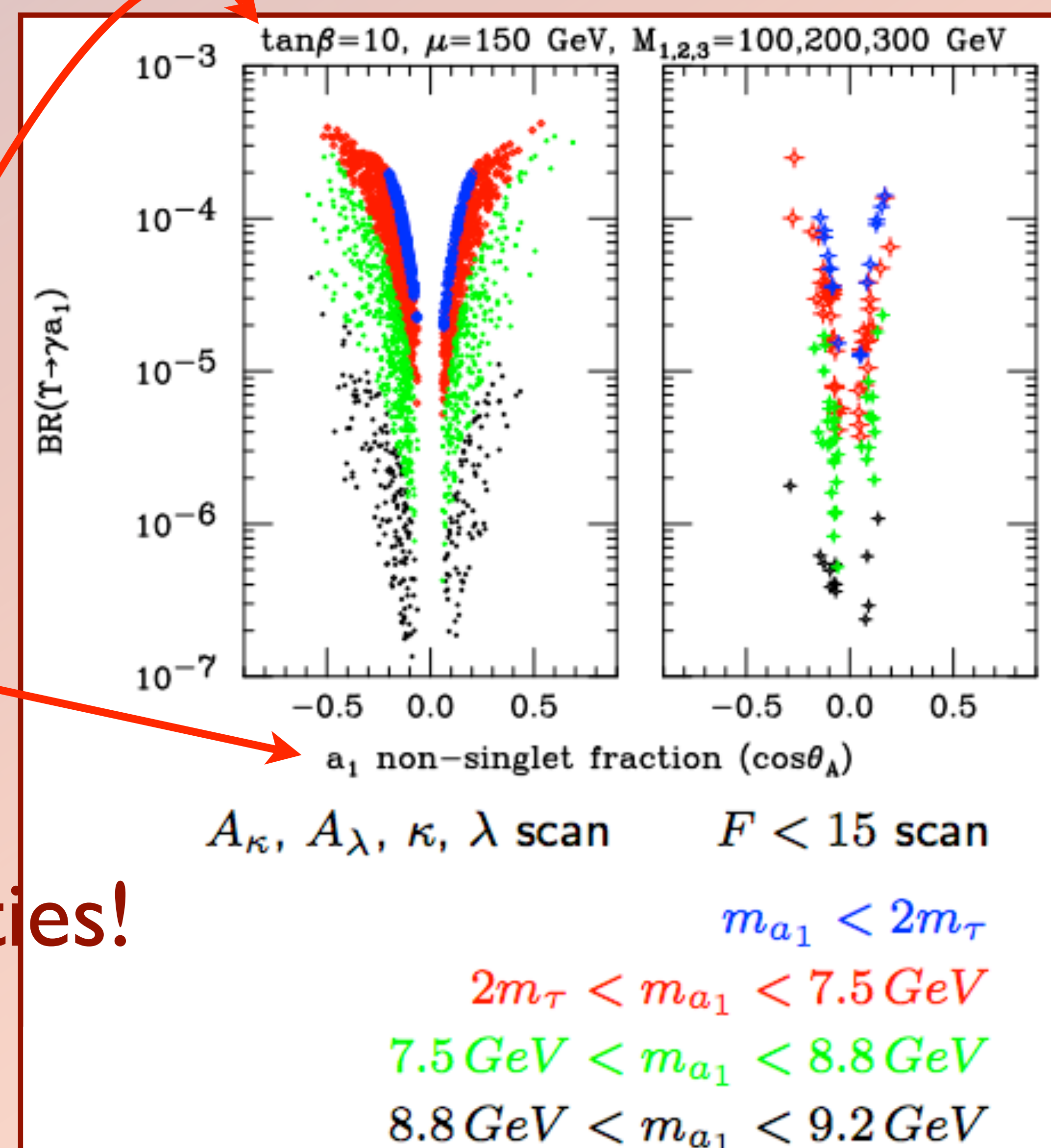
R.D., J. Gunion and B. McElrath, hep-ph/0612031

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

(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!

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CLEO, arXiv:0807.1427 [hep-ex]

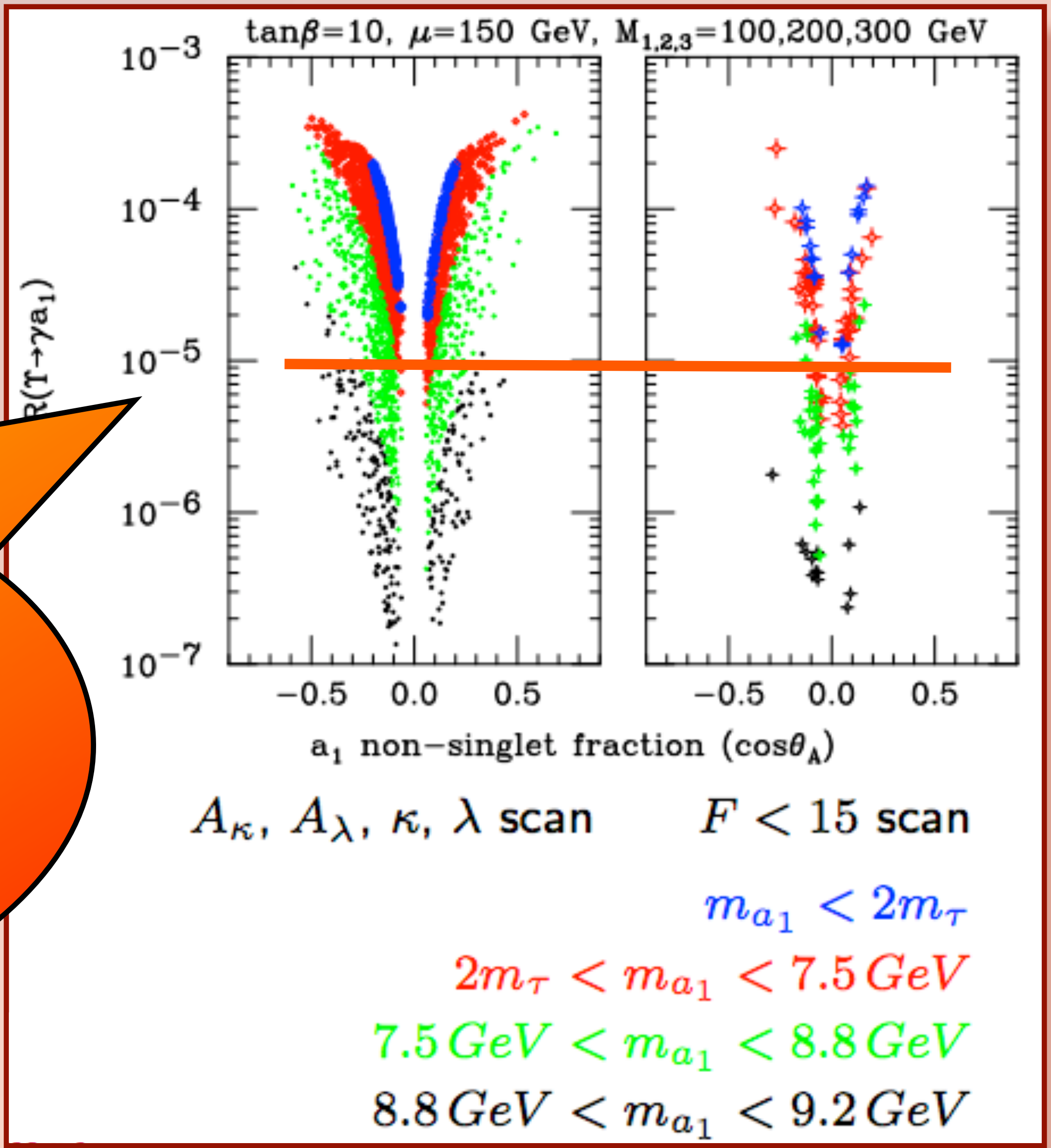
BaBar, arXiv:0902.2176 [hep-ex]

BaBar, arXiv:0906.2219 [hep-ex]

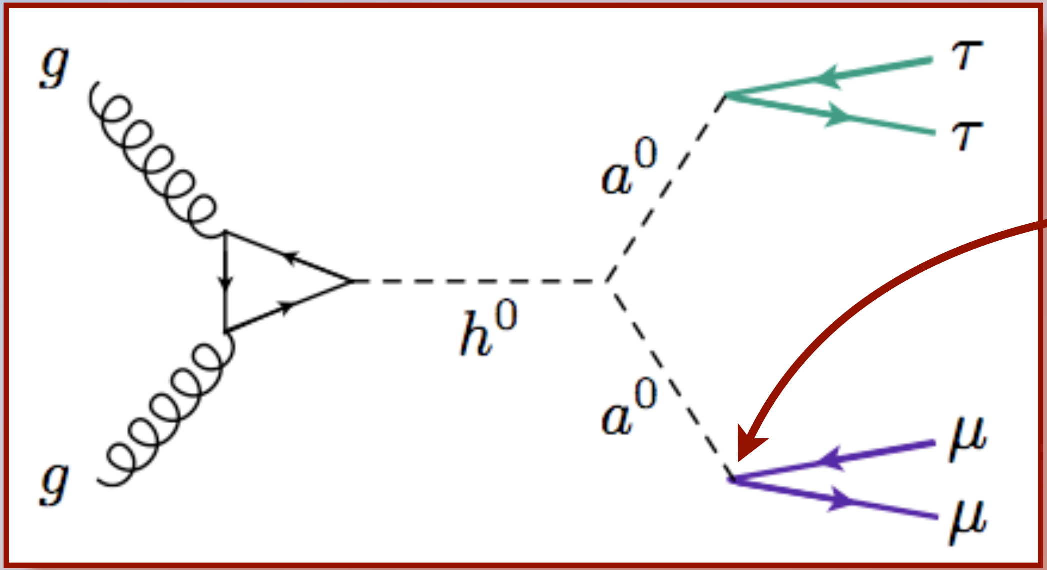
Limits typically require

$$m_a \gtrsim 8 \text{ GeV}$$

and are easier to satisfy for smaller $\tan\beta$.



Tevatron searches for $h \to aa \to 4\tau$



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

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

smaller but cleaner!

DØ-search for $h \to 2\mu 2\tau$

DØ, arXiv:0905.3381 [hep-ex] (PRL)

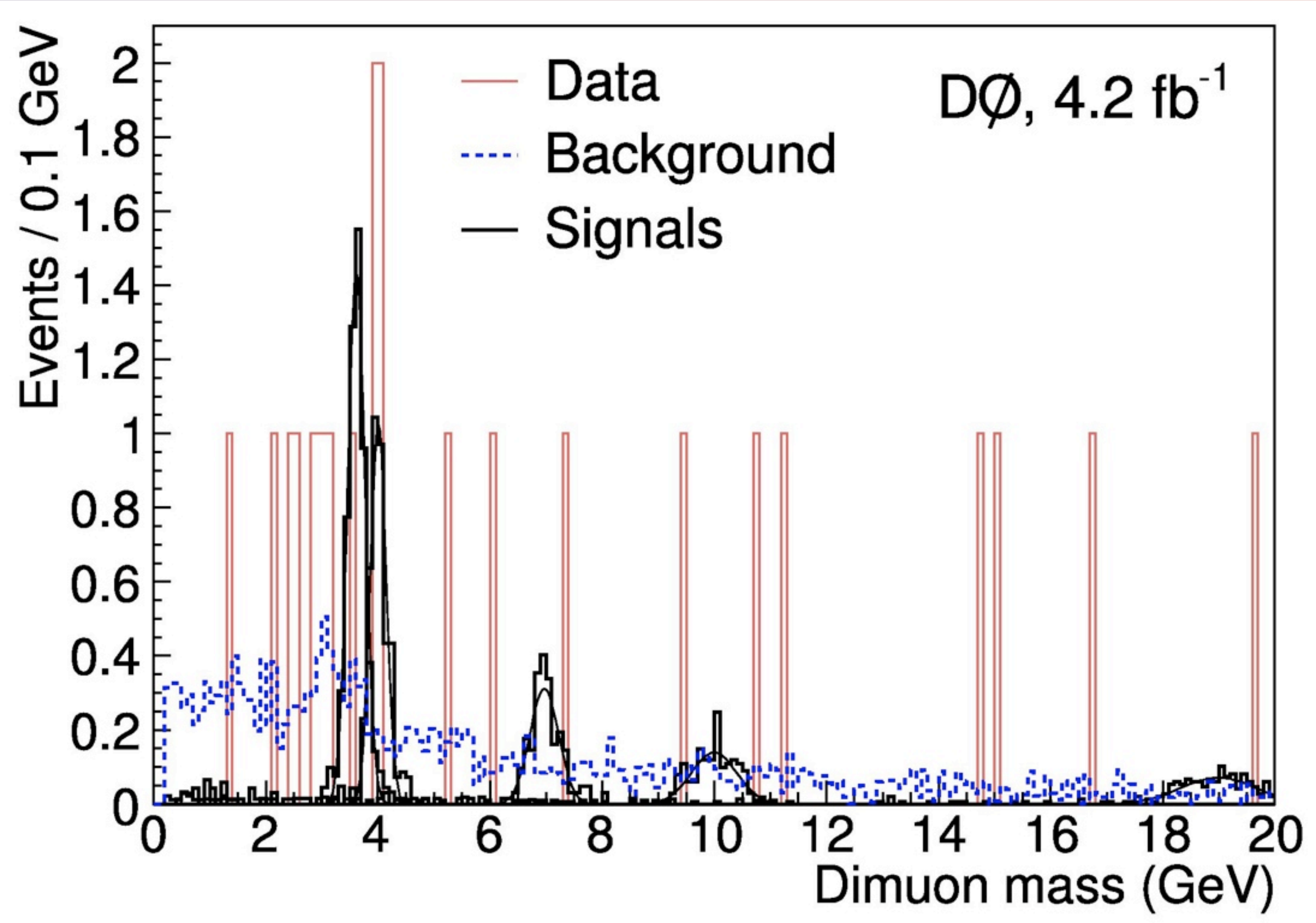


FIG. 2: The dimuon invariant mass for events passing all selections in data, background, and $2\mu 2\tau$ signals for M_a = 3.6, 4, 7, 10, and 19 GeV. $\sigma(p\bar{p}\to h+X)$=1.9 pb is assumed, BR($h\to aa$)=1, and M_h=100 GeV.

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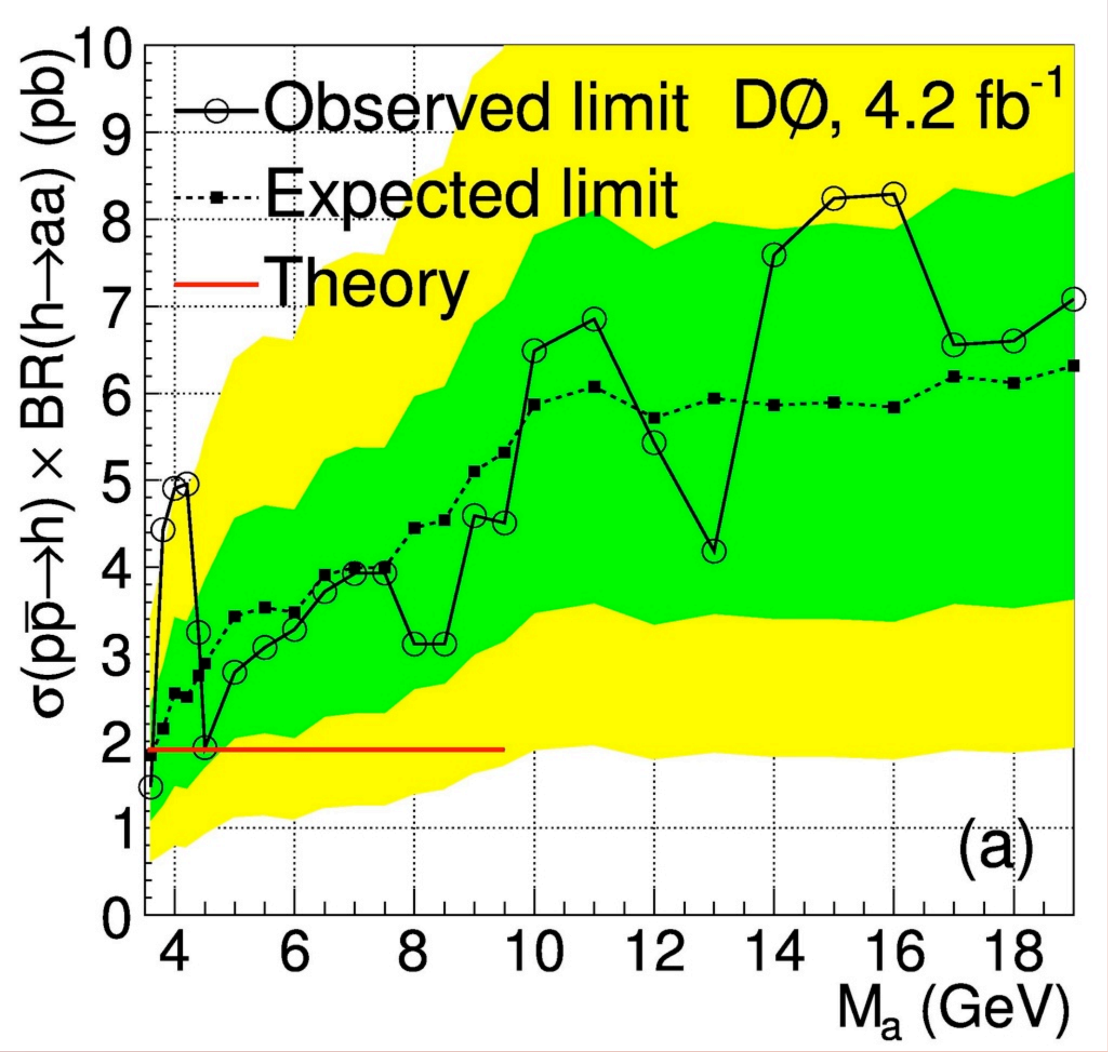


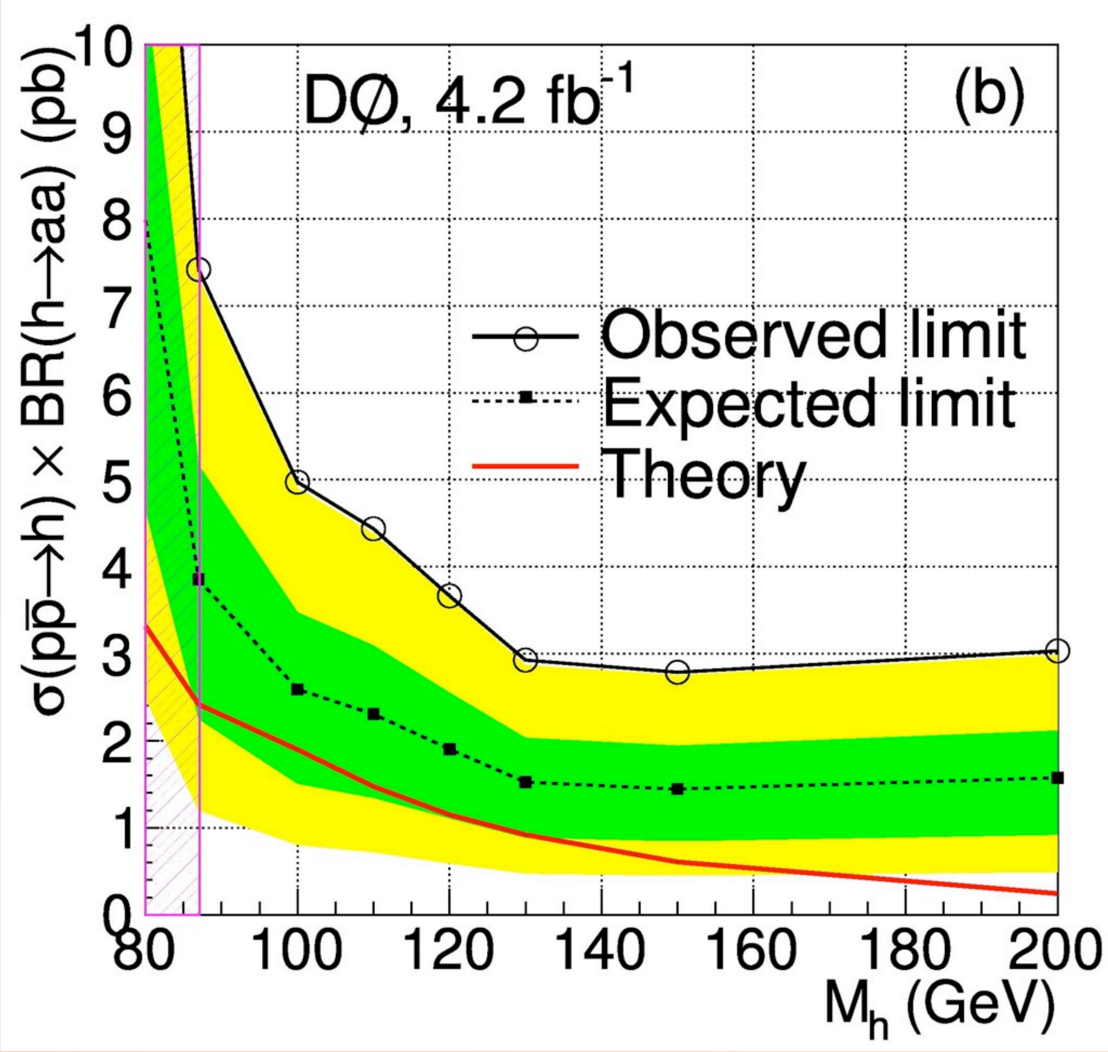
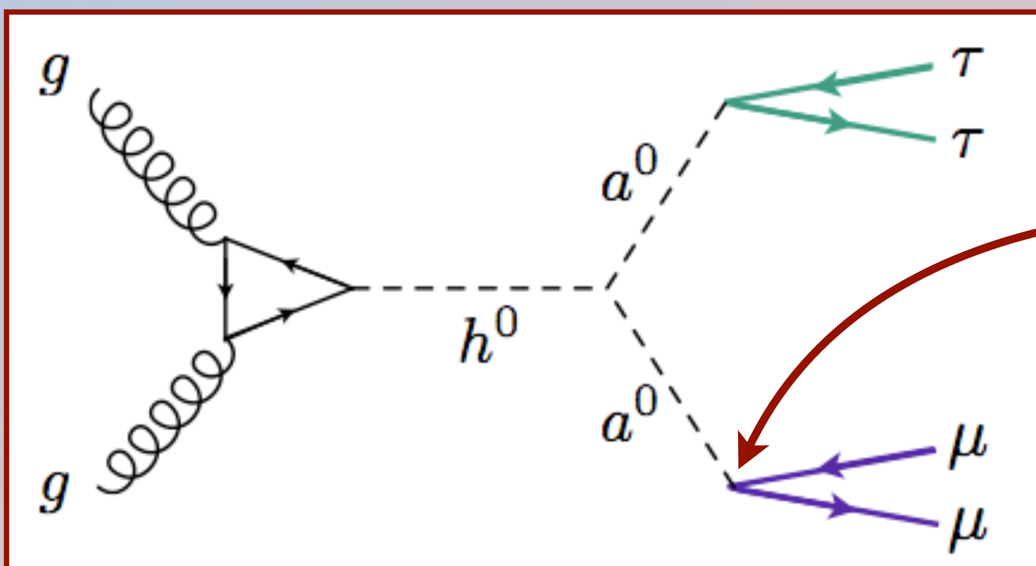


FIG. 3: The expected and observed limits and ± 1 s.d. and ± 2 s.d. expected limit bands for $\sigma(p\bar{p} \to h+X) \times \mathrm{BR}(h \to aa)$, for (a) $M_h = 100$ GeV and (b) $M_a = 4$ GeV. The signal for $\mathrm{BR}(h \to aa) = 1$ is shown by the solid line. The region $M_h < 86$ GeV is excluded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

Tevatron searches for $h \to aa \to 4\tau$

DØ, arXiv:0905.3381 [hep-ex]



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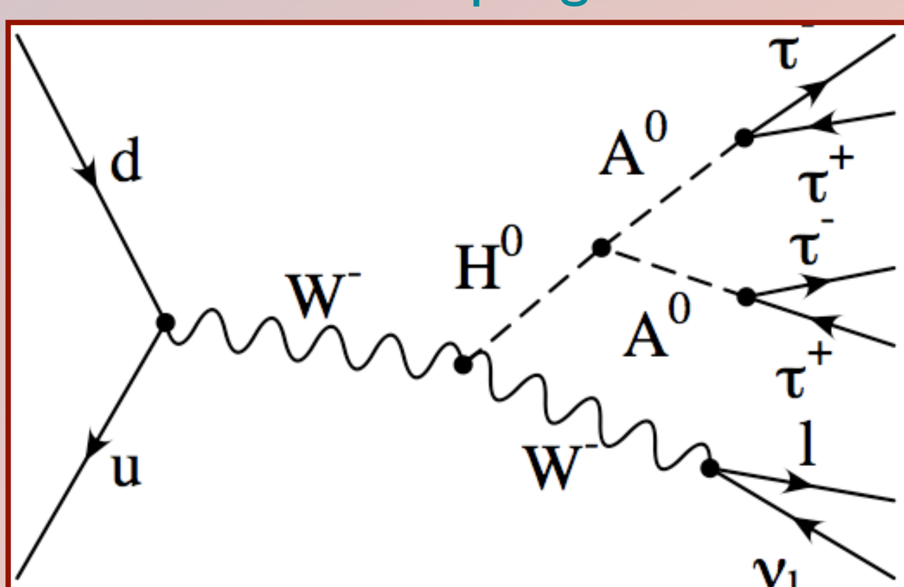
smaller but cleaner!

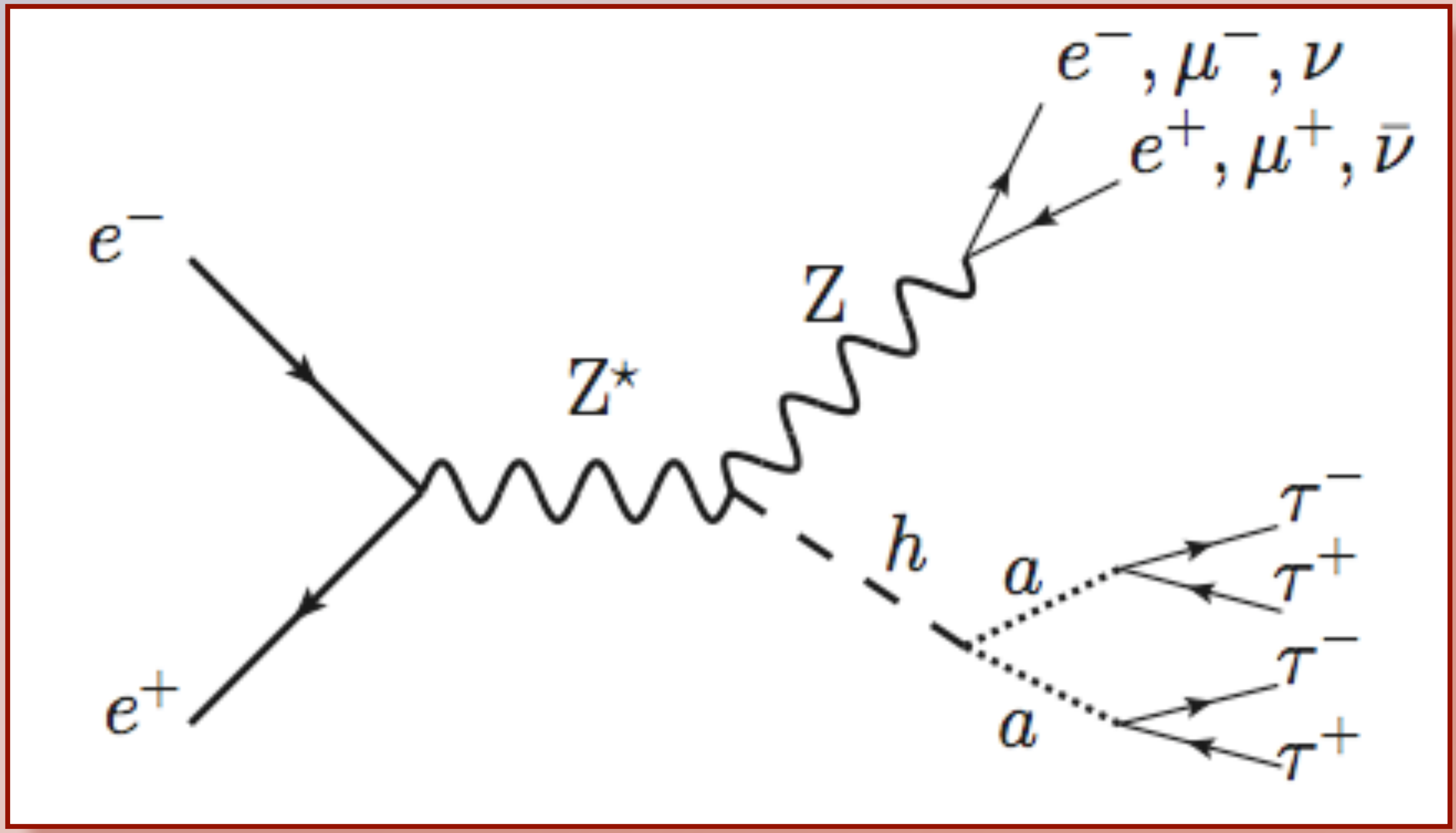
should be relatively easy at the LHC
~500 events with $1\mathrm{fb}^{-1}$

S. Wilbur, CDF, in progress



Aleph search for $h \rightarrow aa \rightarrow 4\tau$

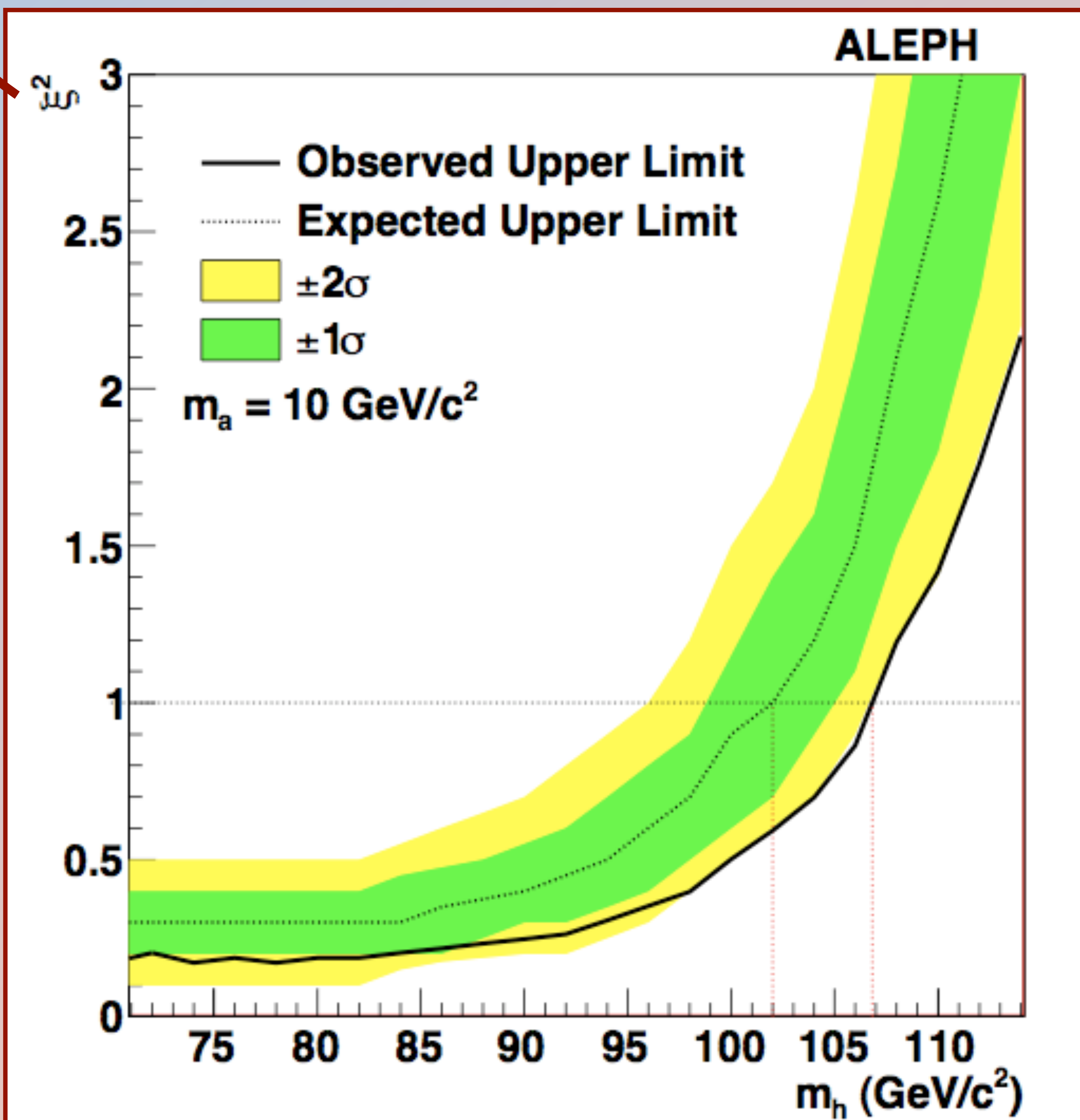
K. Cranmer, Aleph, arXiv:1003.0705 [hep-ex]

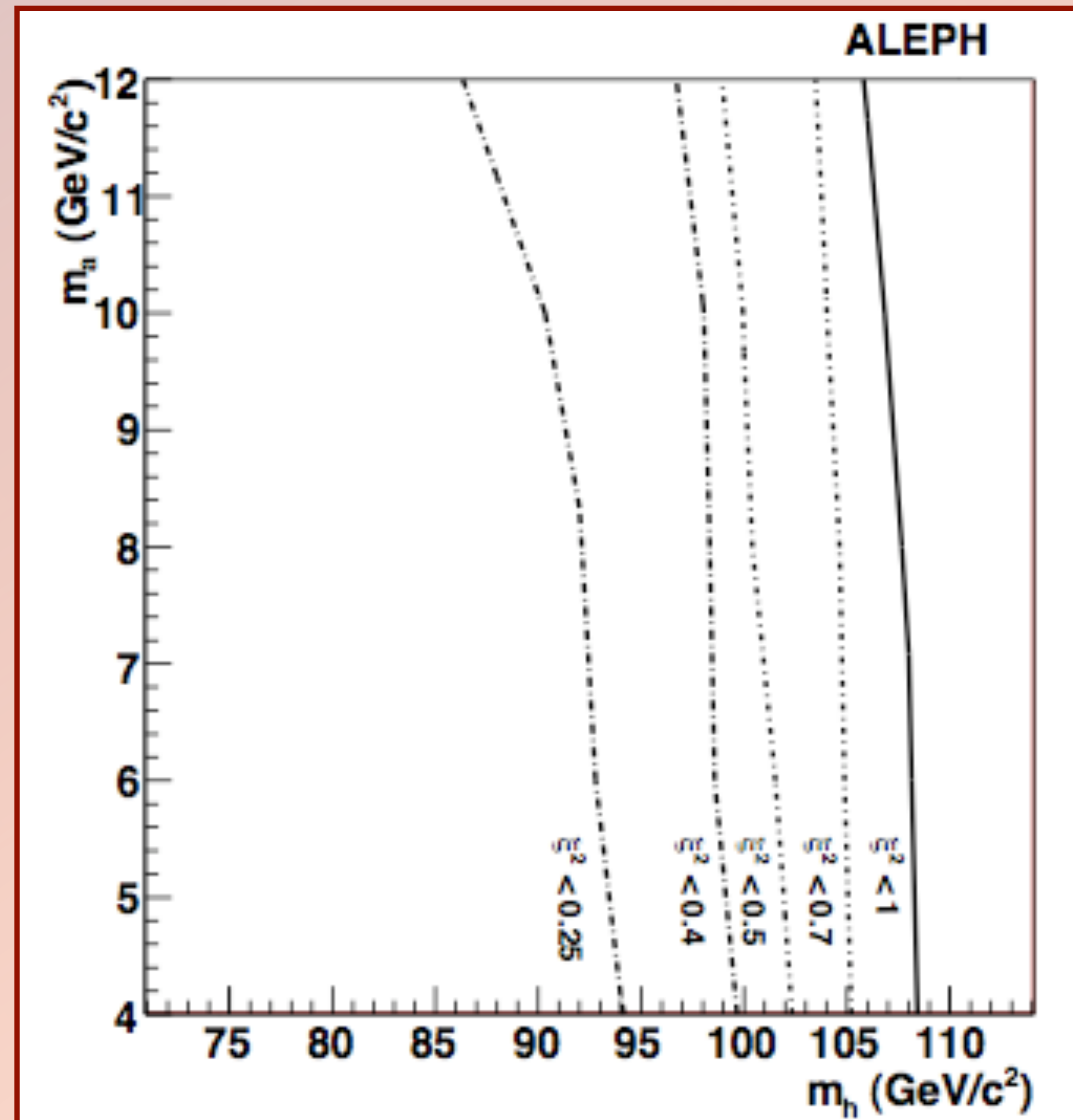


Aleph search for $h \to aa \to 4\tau$

$$\xi^2 = \frac{\sigma(e^+e^- \to Zh)}{\sigma_{SM}(e^+e^- \to Zh)} \times B(h \to aa) \times B(a \to \tau^+\tau^-)^2$$

K. Cranmer, Aleph, arXiv:1003.0705 [hep-ex]

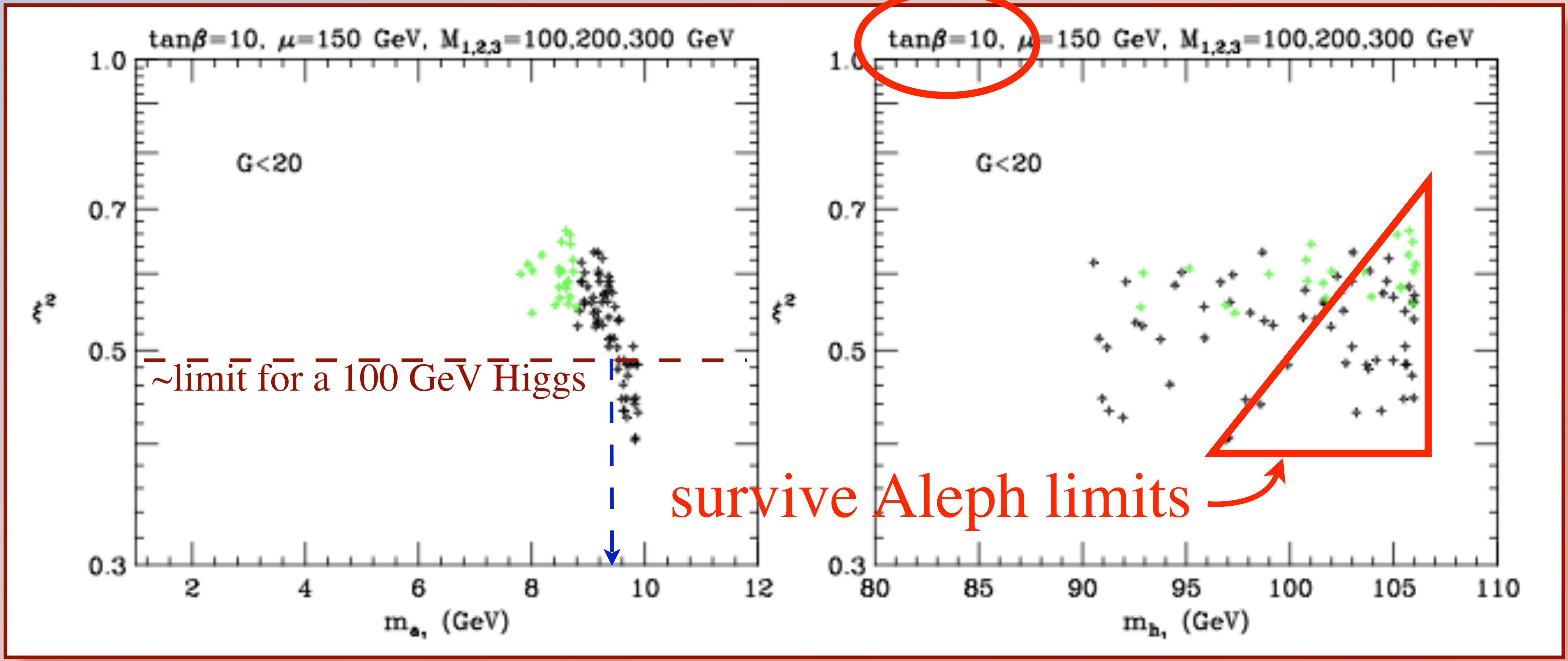




Aleph search for $h \to aa \to 4\tau$

R.D. and J. Gunion, arXiv:1002.1971 [hep-ph]

NMSSM scan over trilinear and soft-trilinear couplings, scalars fixed to 300 GeV



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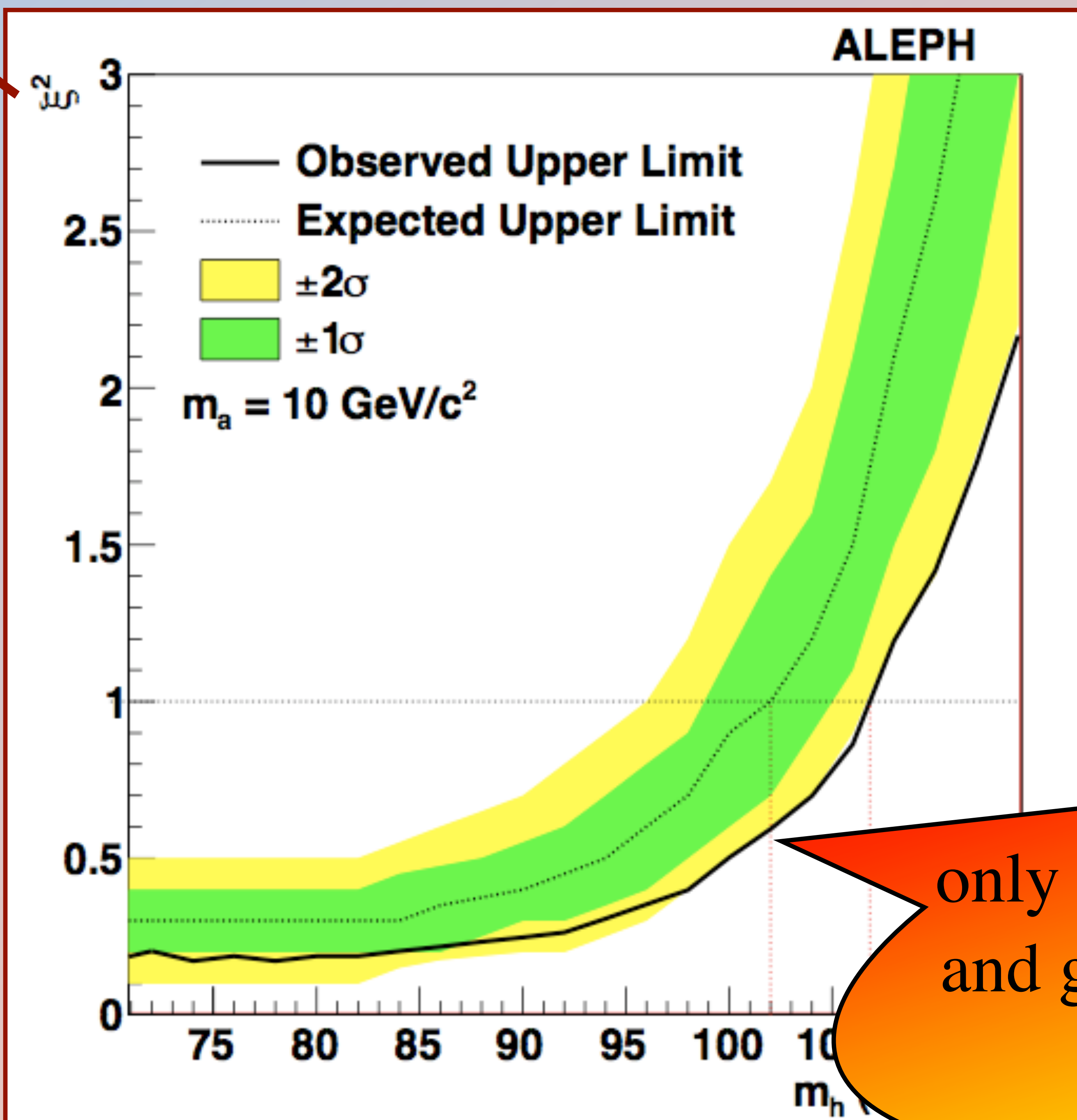
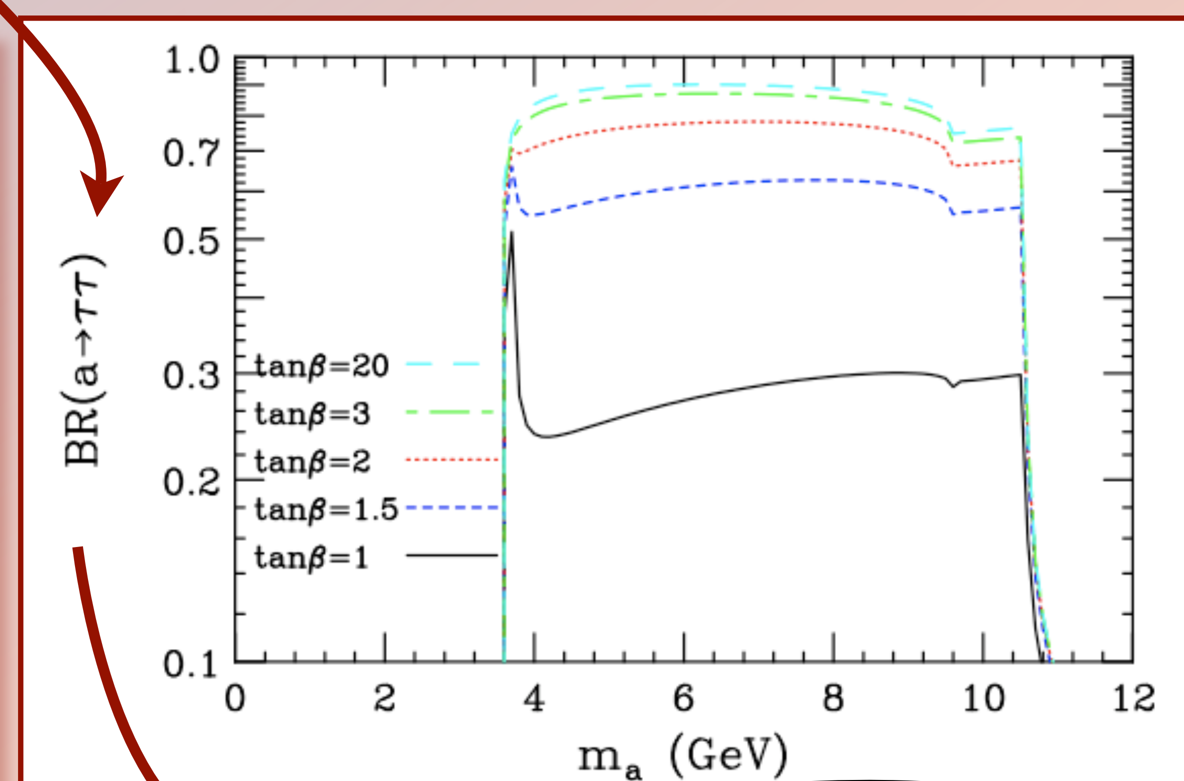
R.D. and J. Gunion, arXiv:1002.1971 [hep-ph]



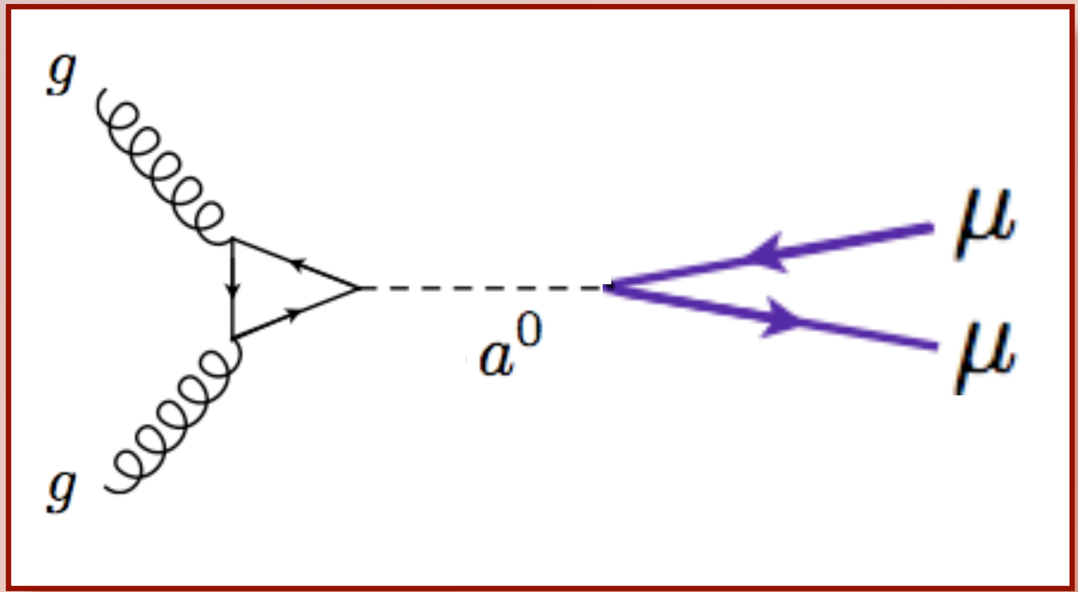


Limits allow $m_h \simeq 100$ GeV only for $m_a \simeq 10$ GeV when $\tan\beta > 3$ and generically for $\tan\beta \lesssim 2$

Light CP odd Higgs at Tevatron and LHC

R.D. and J. Gunion, arXiv:0911.2460 [hep-ph]

Looking for direct production of A:



- CDF and DØ can improve on Babar limits especially for heavier CP odd Higgs
- at the LHC we might discover a light CP odd Higgs soon:

integrated luminosity (fb^{-1}) needed for 5σ:

Case	$m_a = 8$ GeV	$m_a = M_{\Upsilon_{1S}}$	$m_a \lesssim 2m_B$
ATLAS LHC7	$17/r^2$	$63/r^2$	$9/r^2$
ATLAS LHC10	$13/r^2$	$48/r^2$	$7/r^2$
ATLAS LHC14	$10/r^2$	$37/r^2$	$5.4/r^2$

$\cos\theta_A = 0.1$

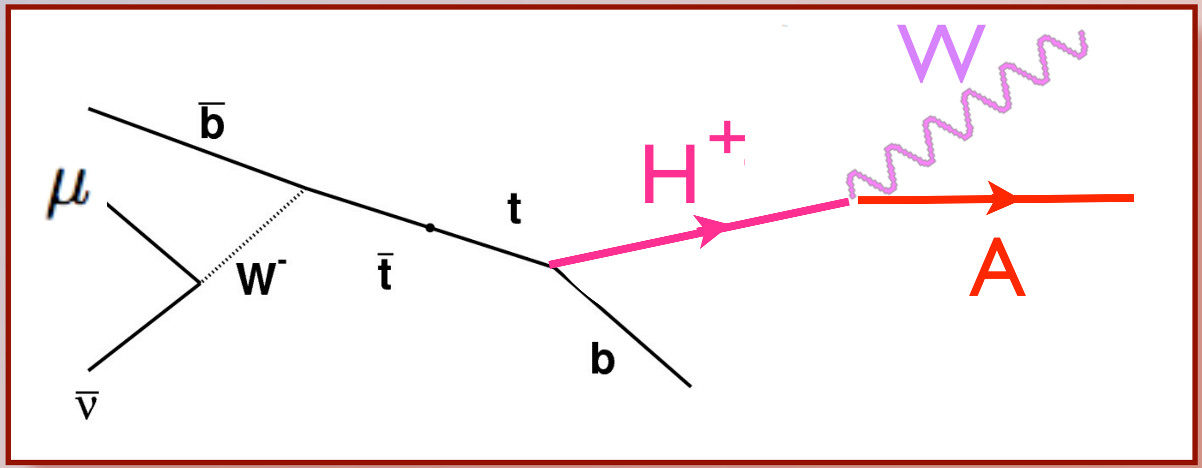
$\tan\beta = 10$

$\epsilon_{ATLAS} = 0.1 \times r$

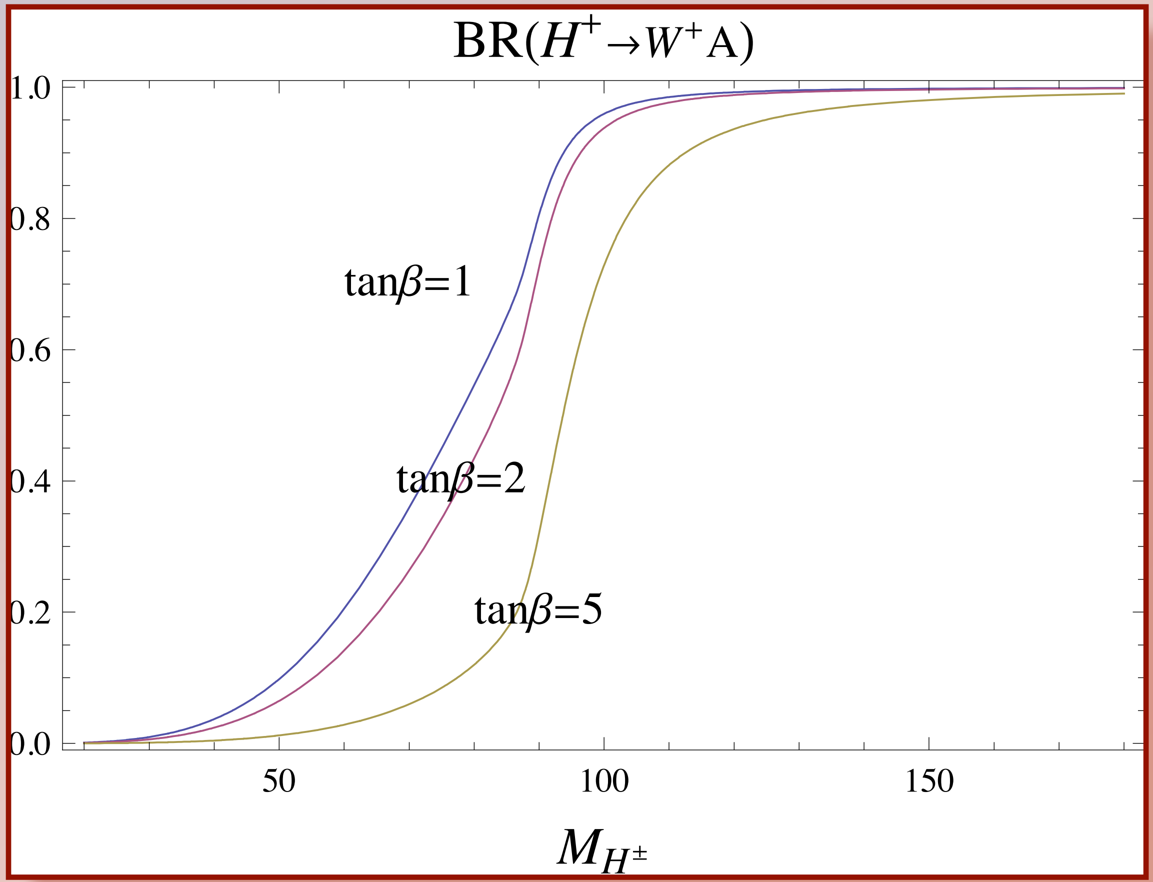
thanks to Yi Yang and Hal Evans

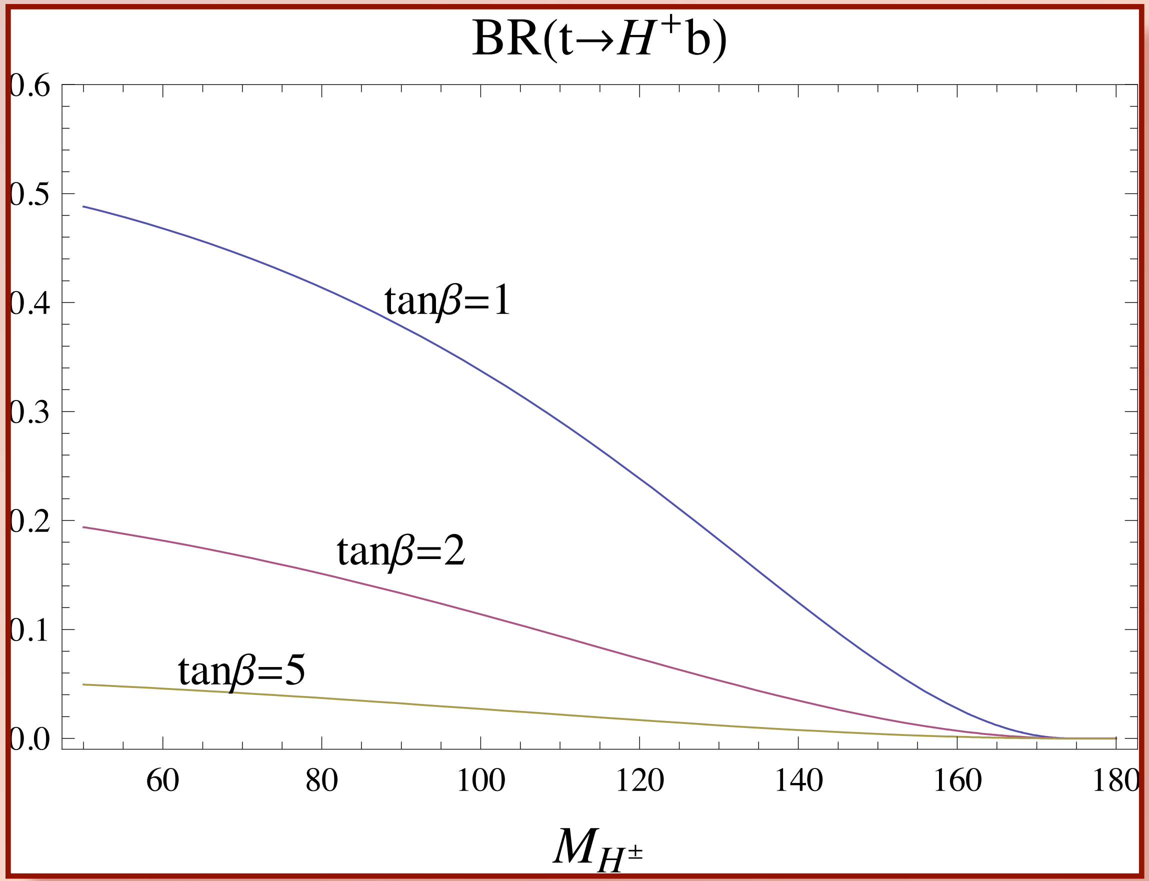
Charged Higgs in Top quark decays

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



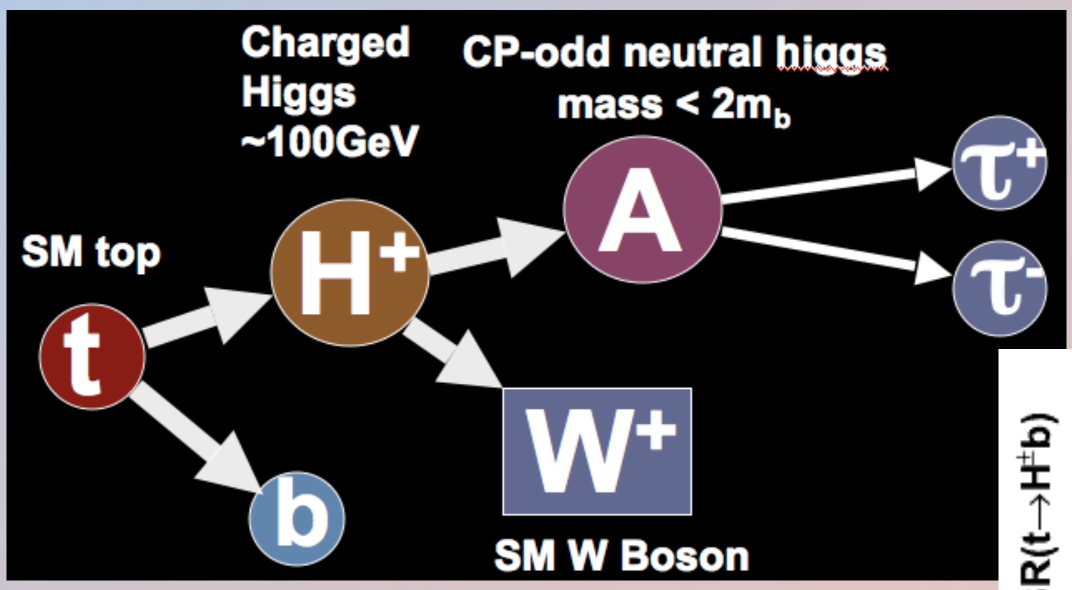
In MSSM:

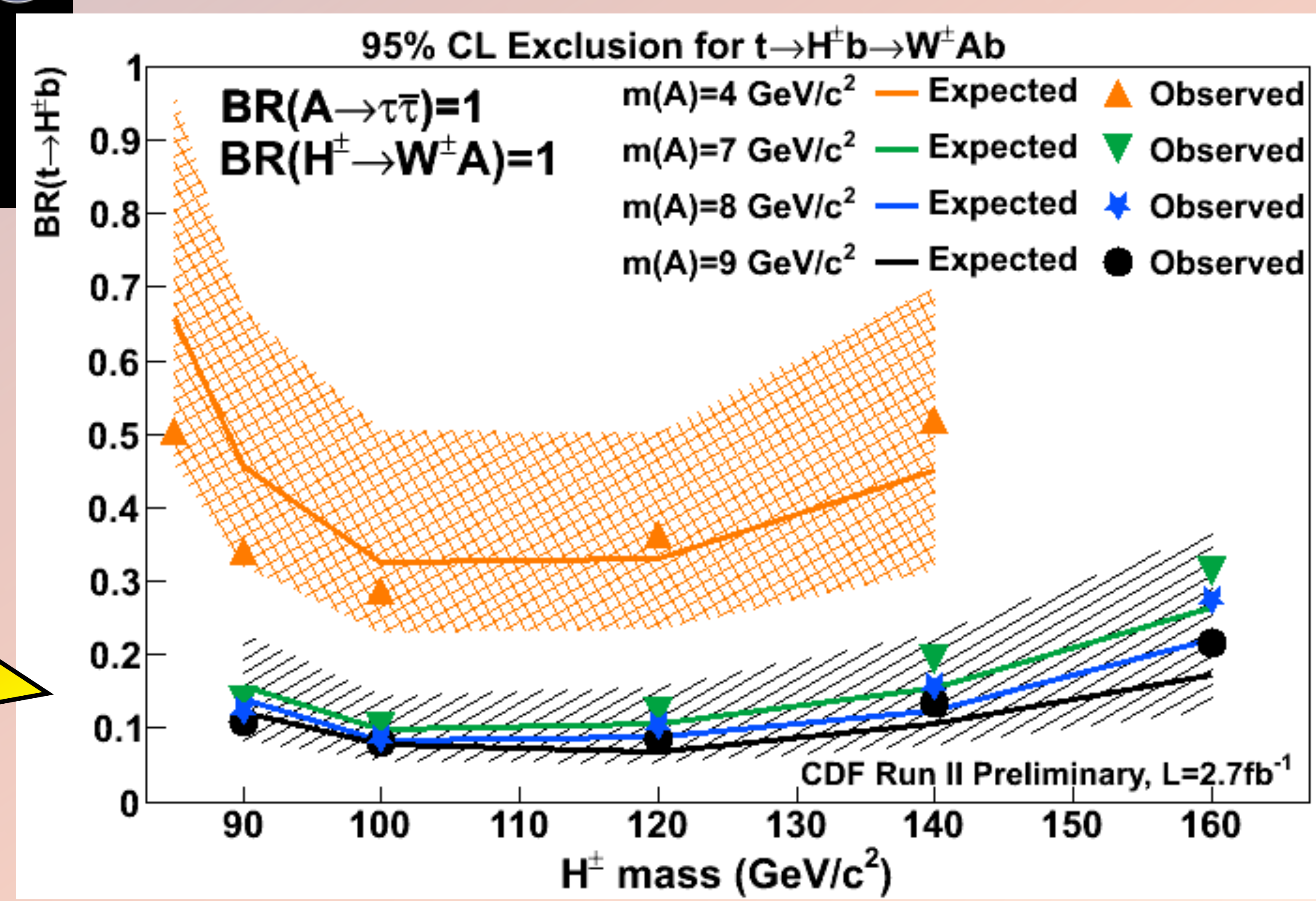




CDF search for charged Higgs

R. Erbacher, A. Ivanov, and W. Johnson, CDF, 2010





Limits allow

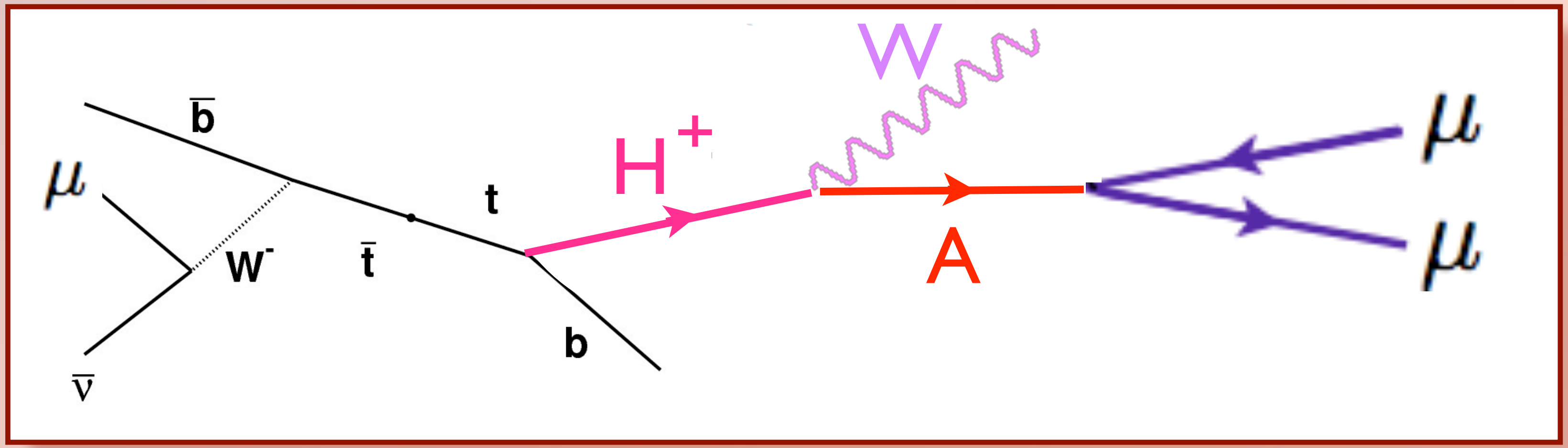
$$Br(t \to H^+ b) \sim 10\%$$

Charged Higgs at the LHC

R.D., E. Lunghi and A. Raval, in progress

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

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



Conclusions

$h \to aa \to 4\tau$, 4q, 4g - simplest possibilities allowing $m_h \simeq 100$ GeV

motivated by naturalness, PEWD, excess of Higgs-like events

dominant decay modes very hard at the LHC (~100s fb^{-1} needed)

Searching for sub-leading decay modes is very promising:

- $gg \to h \to aa \to 2\tau 2\mu$
- $gg \to a \to 2\mu$
- $t \to H^+ b, \quad H^+ \to W^+ a, \quad a \to \mu^+ \mu^-$

possible evidence with $1\,\mathrm{fb}^{-1}$!