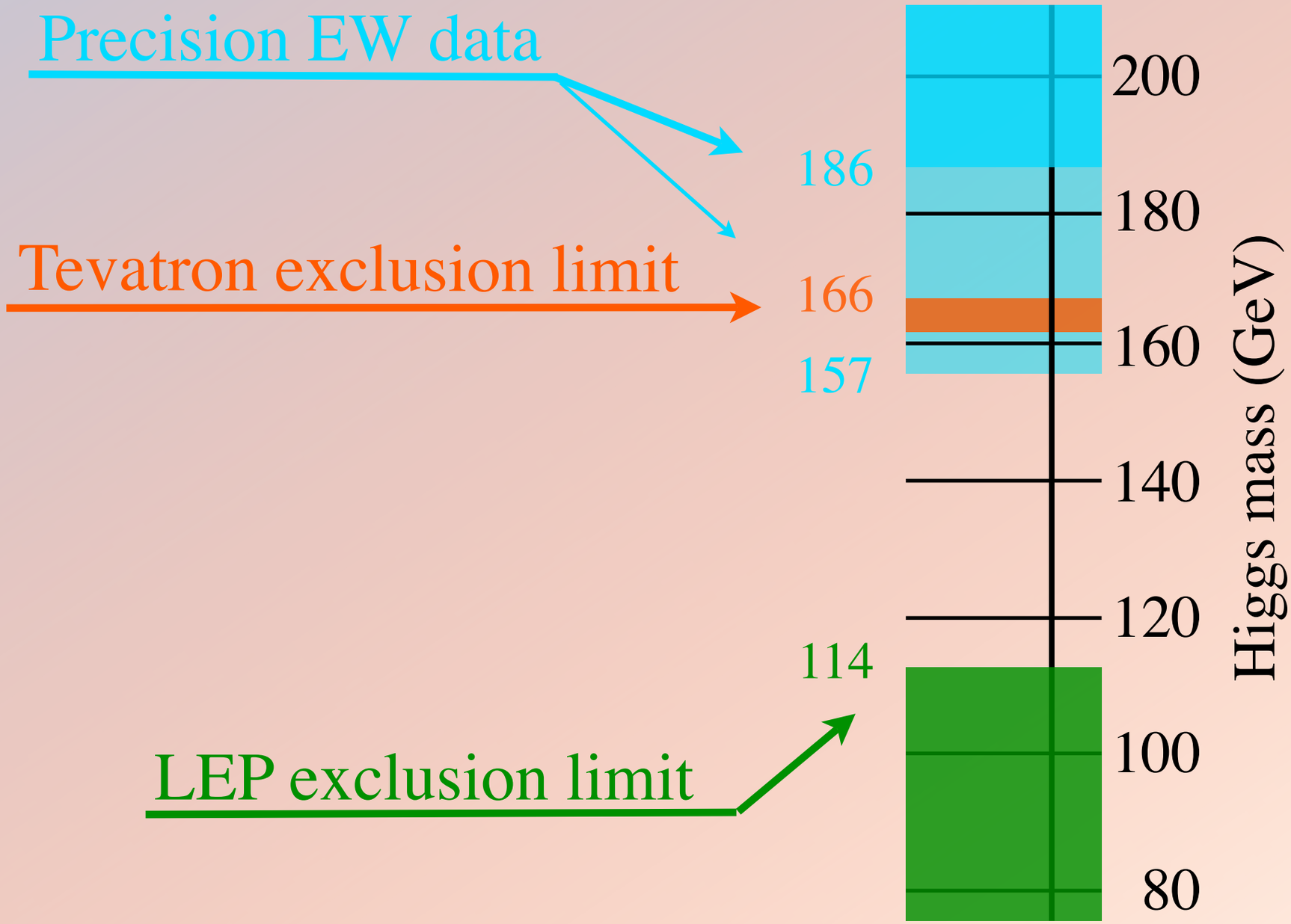
Many Light Higgs Bosons
new constraints and prospects at the LHC

Radovan Dermisek
Indiana University, Bloomington

Where is the Higgs?



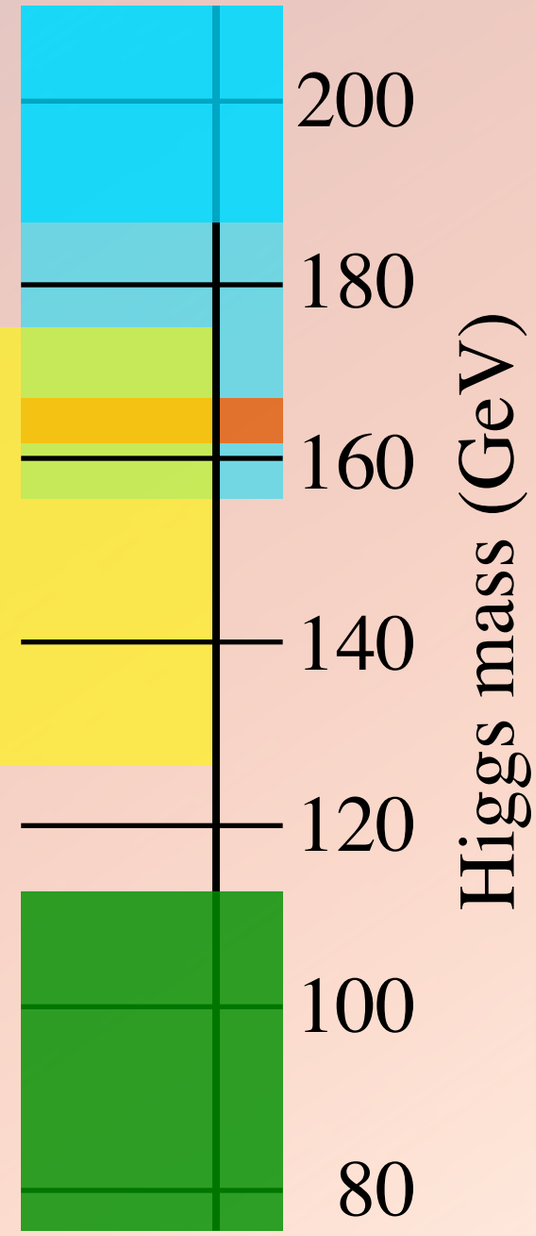
Interesting coincidences

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

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

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

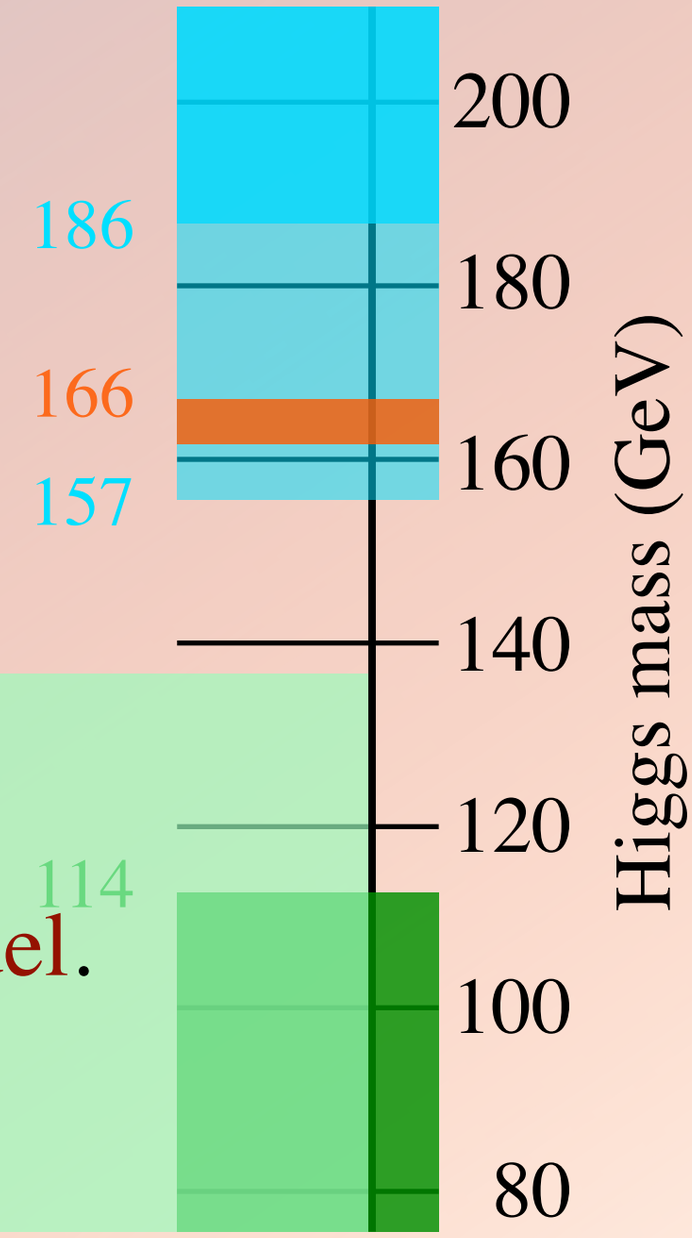


Interesting coincidences

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.



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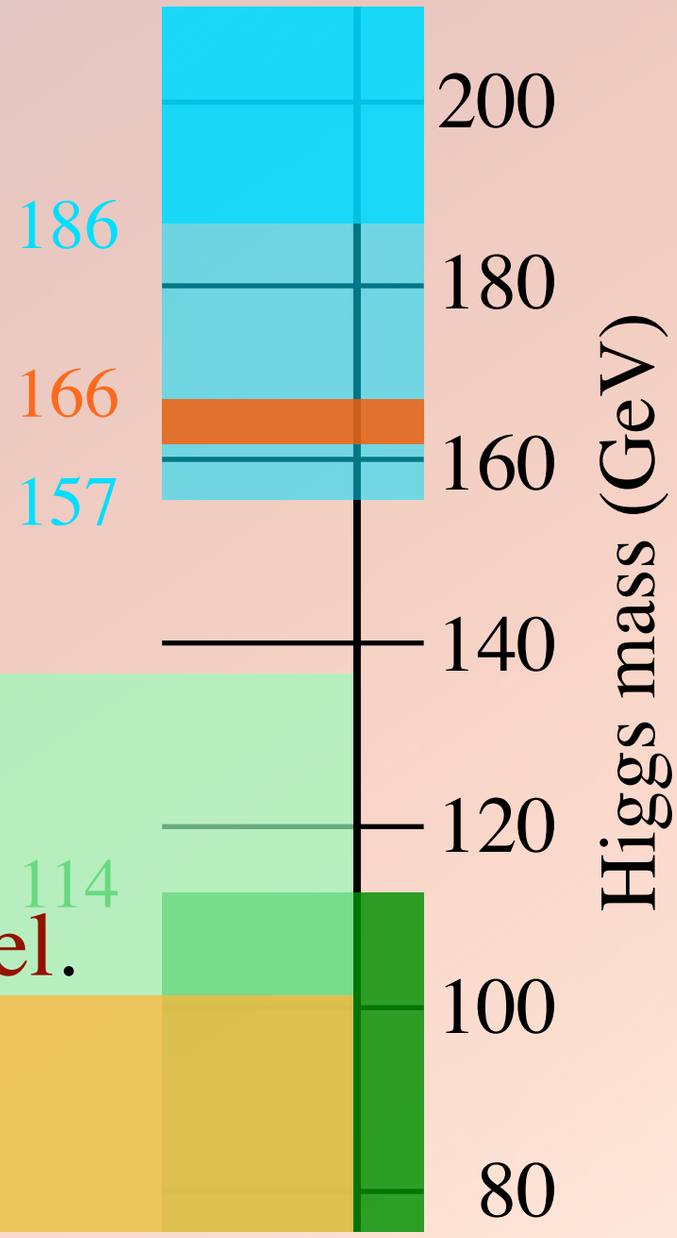
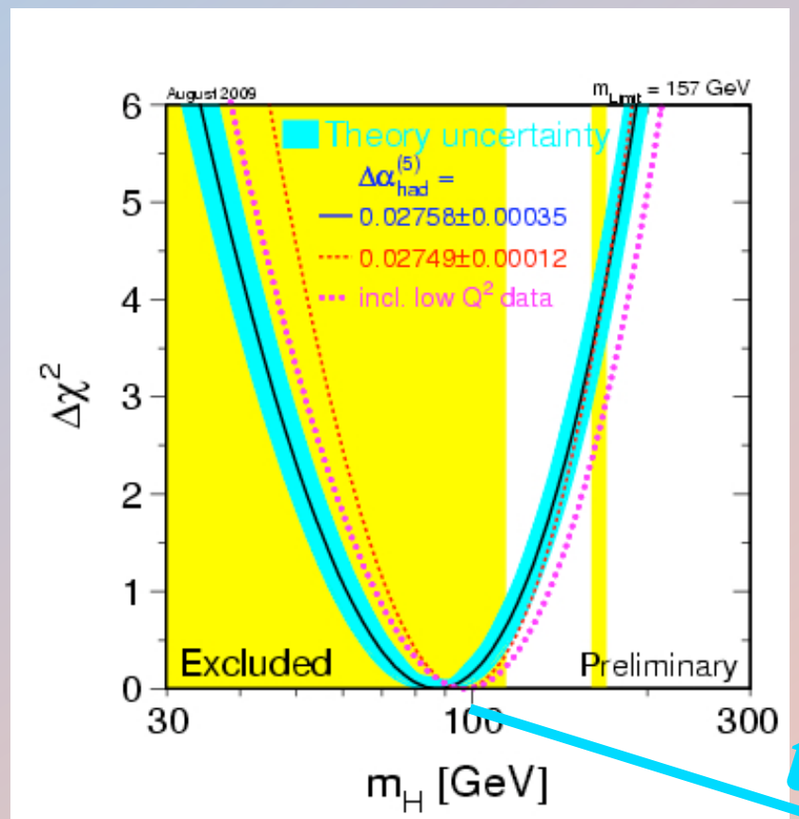


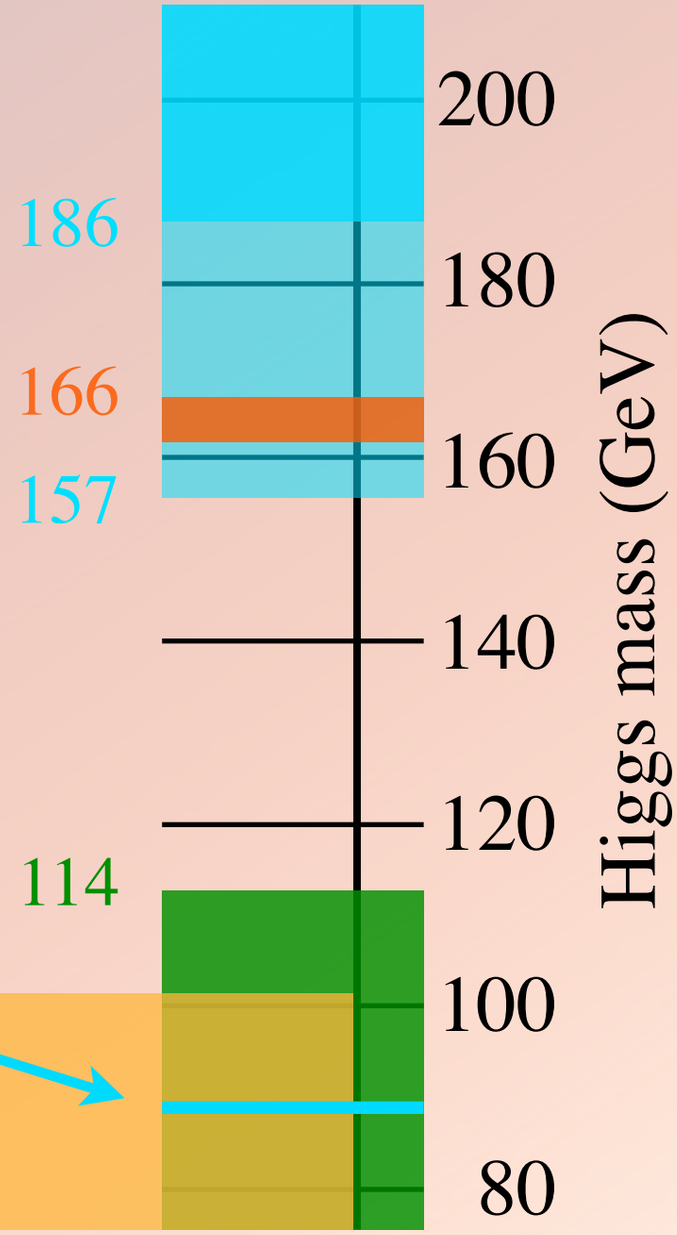
This range corresponds to the Higgs mass predicted in the minimal supersymmetric model.

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

Interesting coincidences



the best fit value



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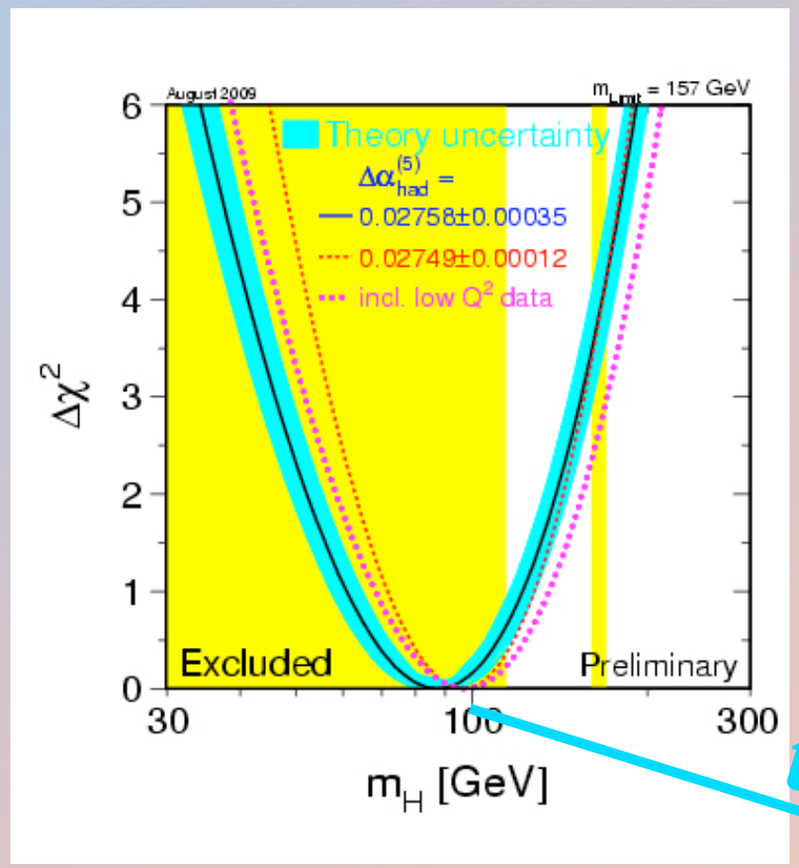
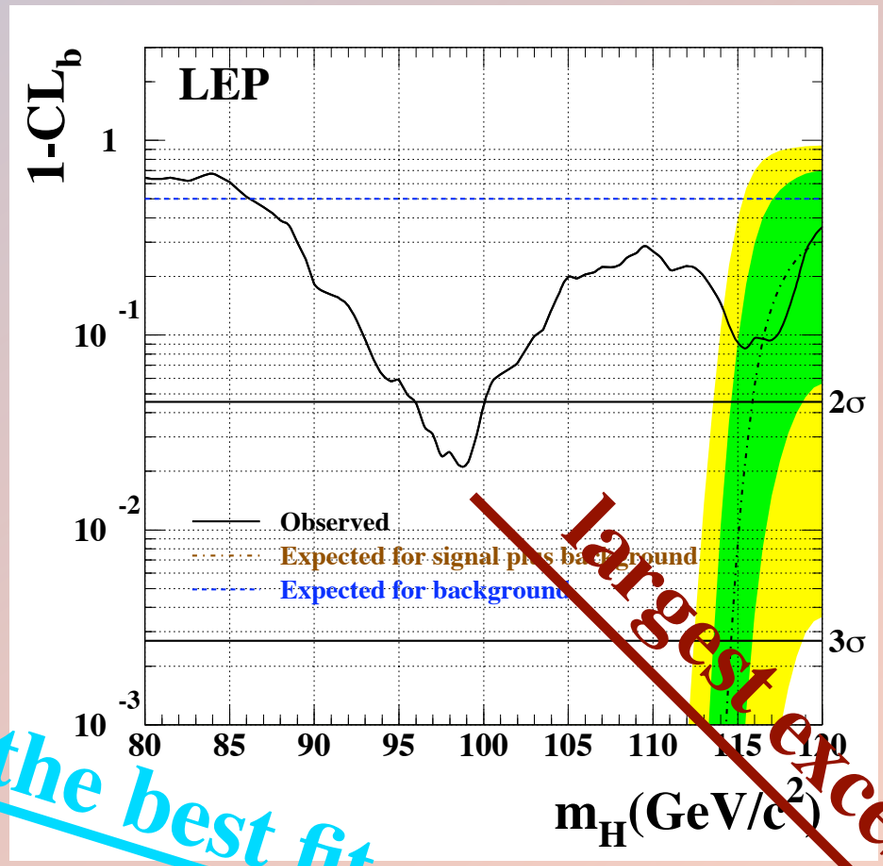
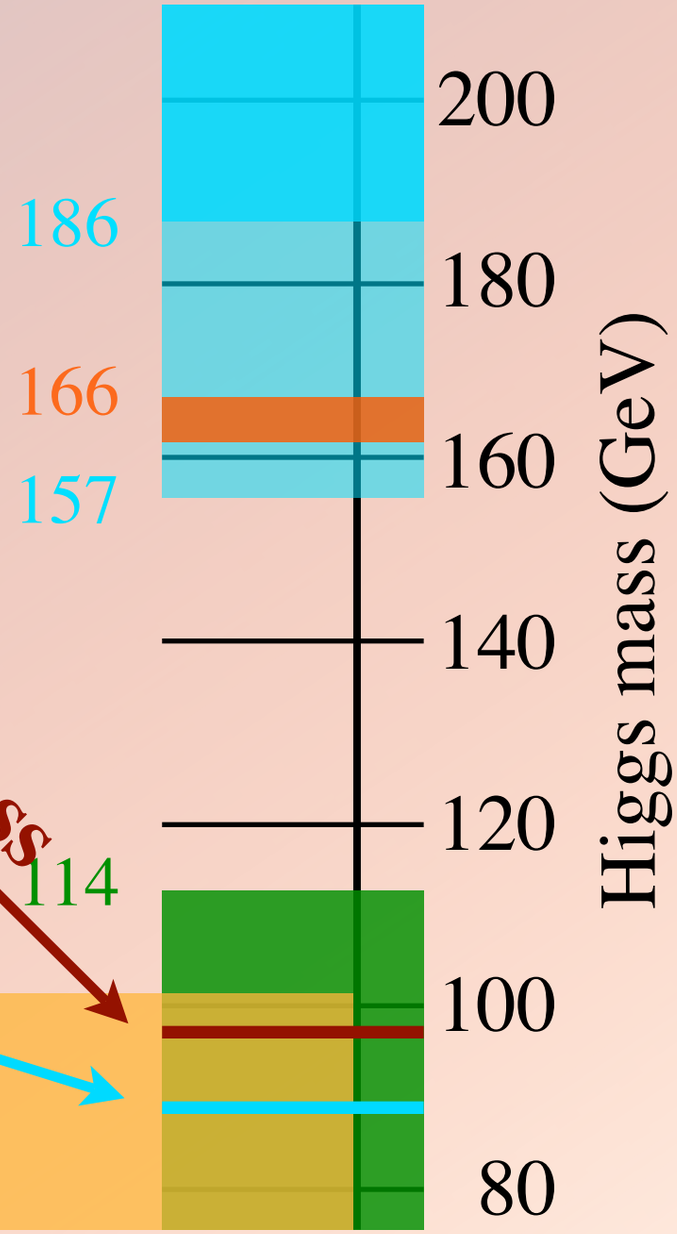






the best fit value

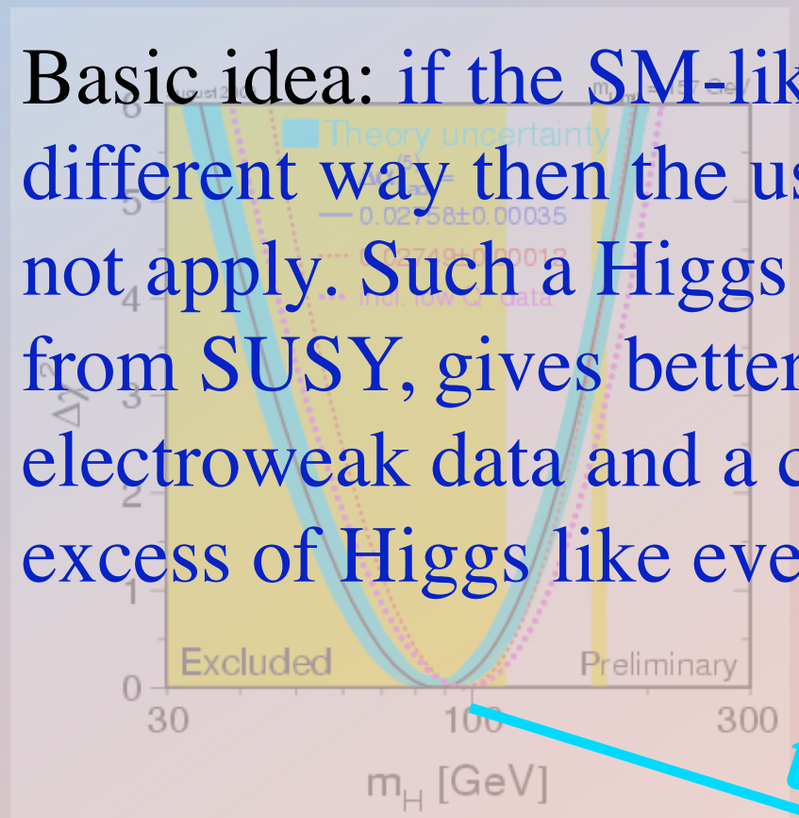
largest excess

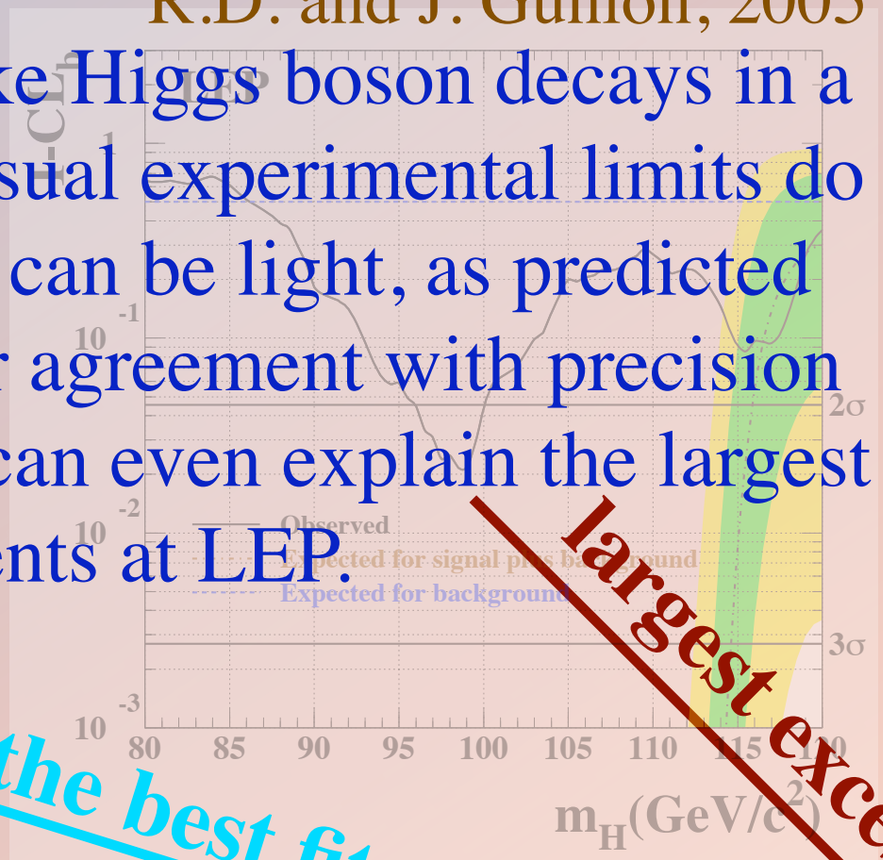
Natural electroweak symmetry breaking in SUSY models is achieved only in this region!

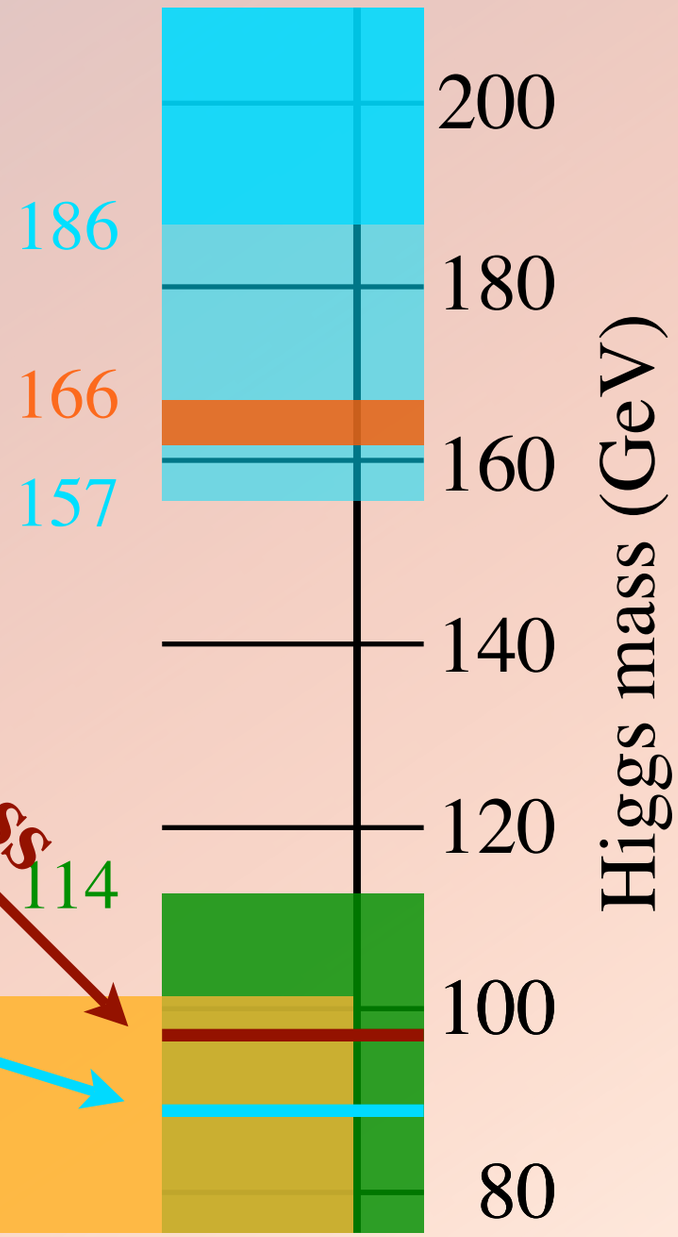
Non-standard Higgs decays

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.

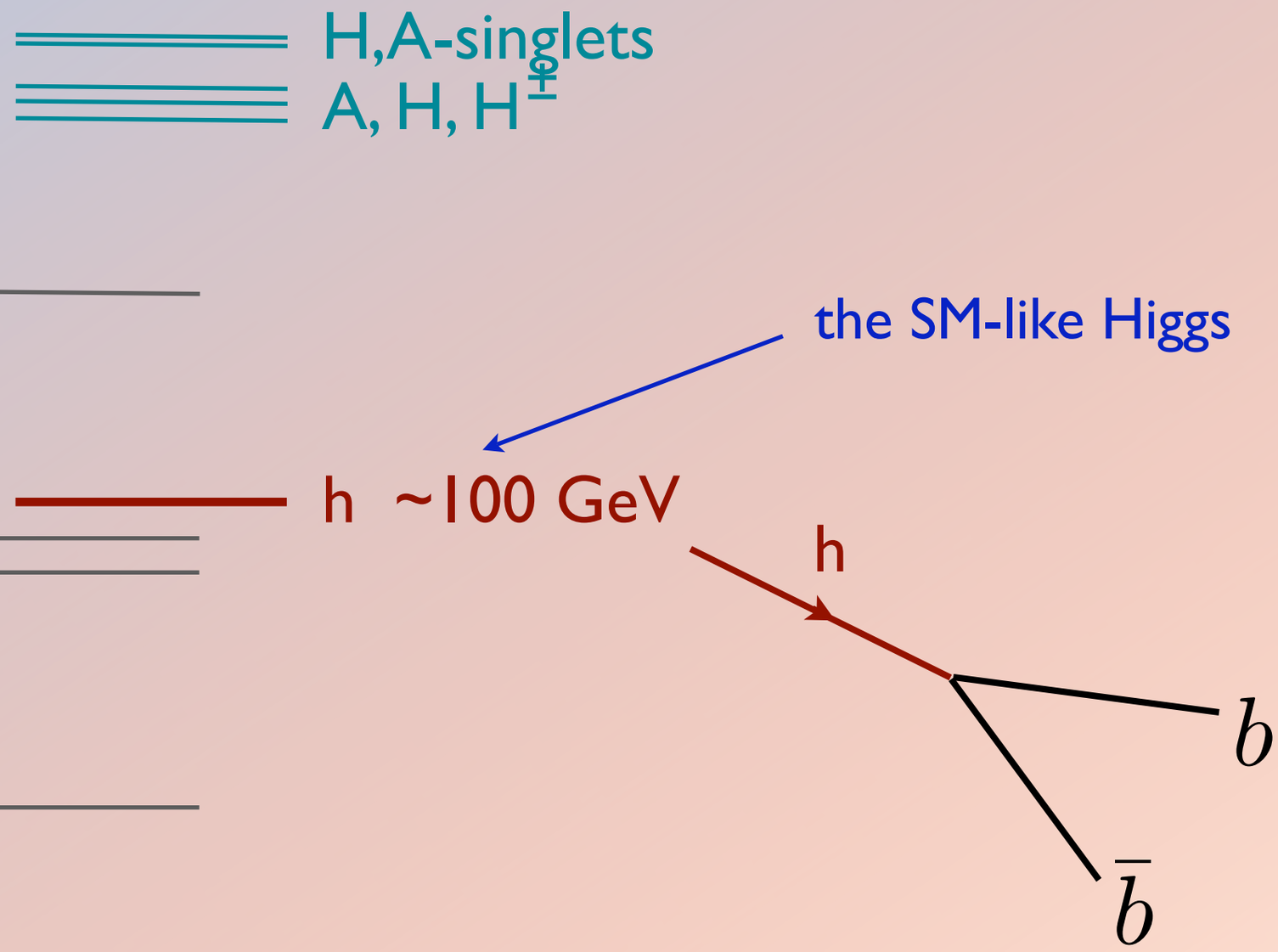






Natural electroweak symmetry breaking in SUSY models is achieved only in this region!

(N)MSSM - the usual story (decoupling)



NMSSM with a light CP odd Higgs

R.D. and J. Gunion, 2005

H-singlet
$A, H, H^{\pm}$

the usual decoupled scenario (for the two Higgs doublet part)

top

the SM-like Higgs

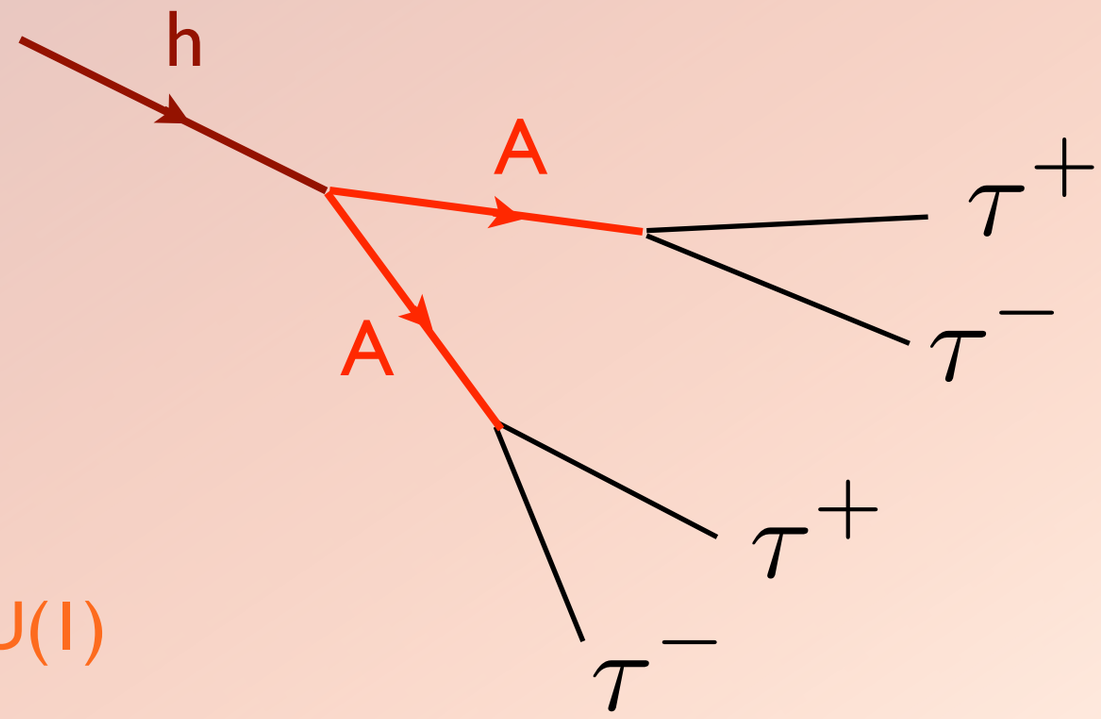
Z
W

h ~100 GeV

10 GeV

A-singlet

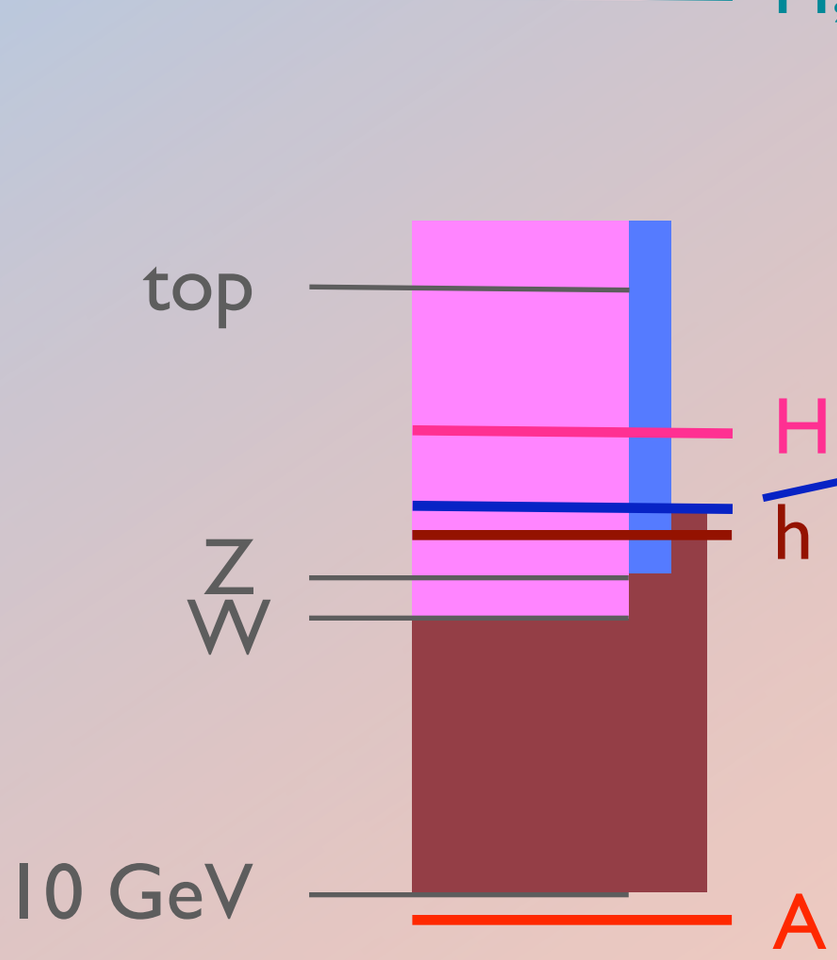
A is light as a result of an approximate global U(1)

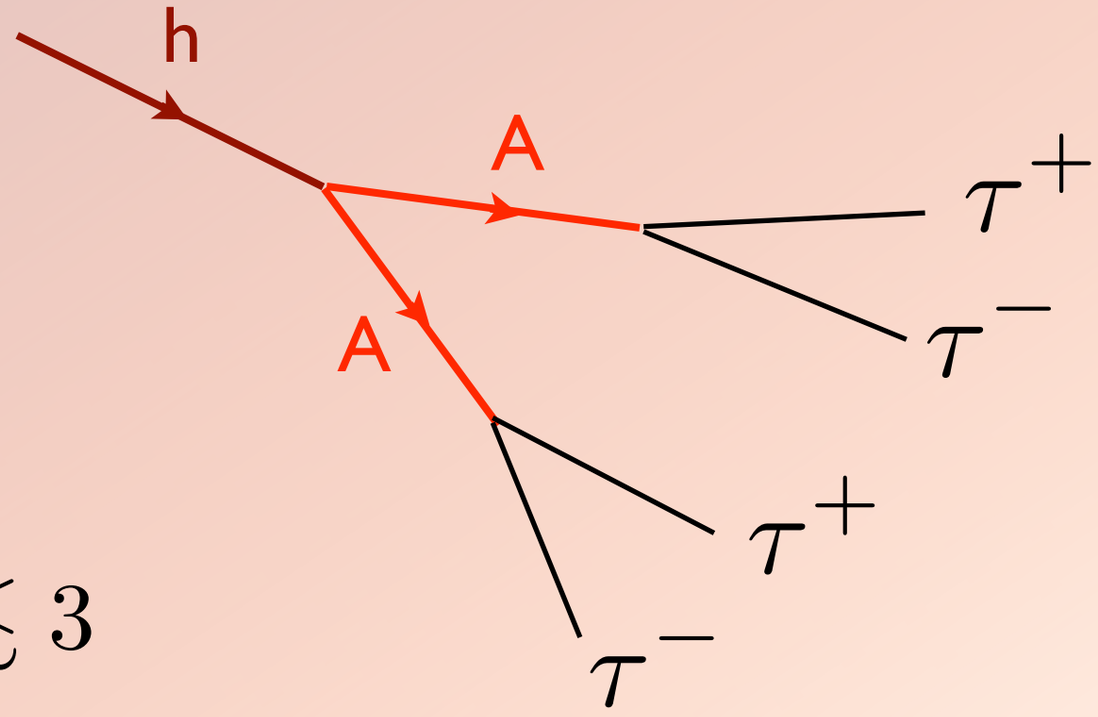


Models with a light doublet-like A

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

H, A-singlets



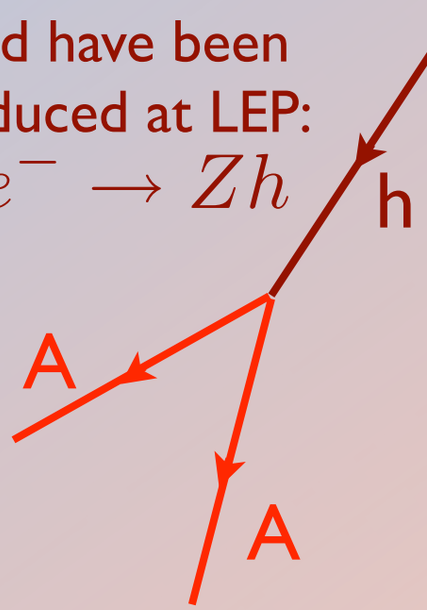


viable e.g. in NMSSM for $\tan\beta \lesssim 3$

Summary of the Light doublet-like CP odd Higgs scenario

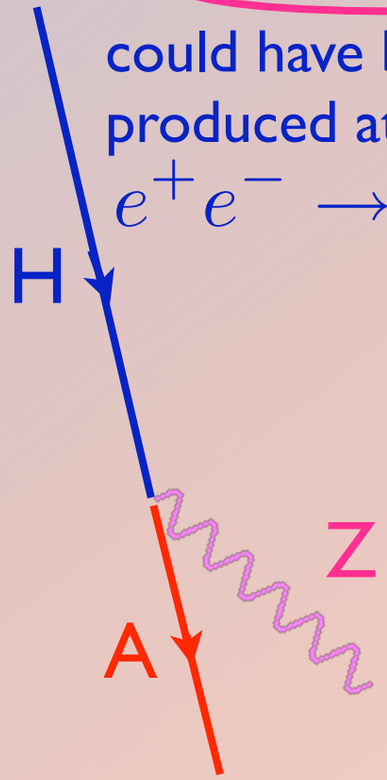
- all the Higgses (from two Higgs doublets) are fairly light
- all the Higgses: h, H, $H^{\pm}$ decay through the CP odd Higgs - A

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



ongoing searches and studies at Aleph, L3, Tevatron, LHC

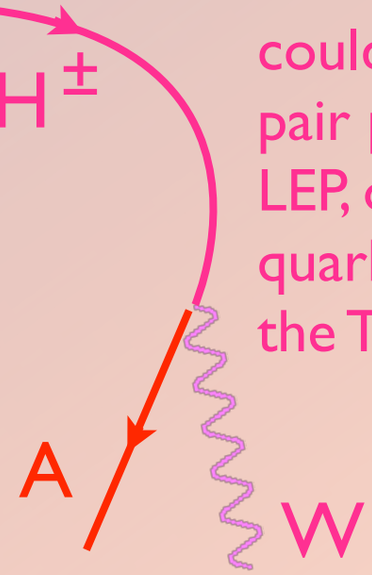
could have been produced at LEP: $e^+e^- \to HA$



no searches or studies

$H^{\pm}$

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



recent search at CDF

could have been produced at B factories

$\Upsilon \to A\gamma$

searches at B factories

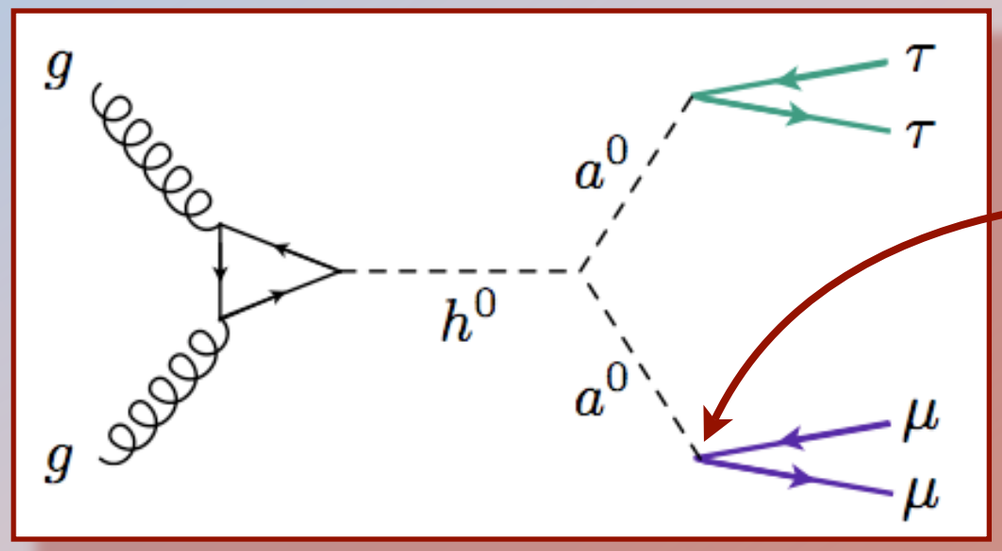
direct production at Tevatron and LHC

talk of J. Gunion

- the extra singlet is not necessary

the scenario can be viable in many other models!

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



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 $h \rightarrow 2\mu 2\tau$

DØ, arXiv:0905.3381 [hep-ex] (PRL)

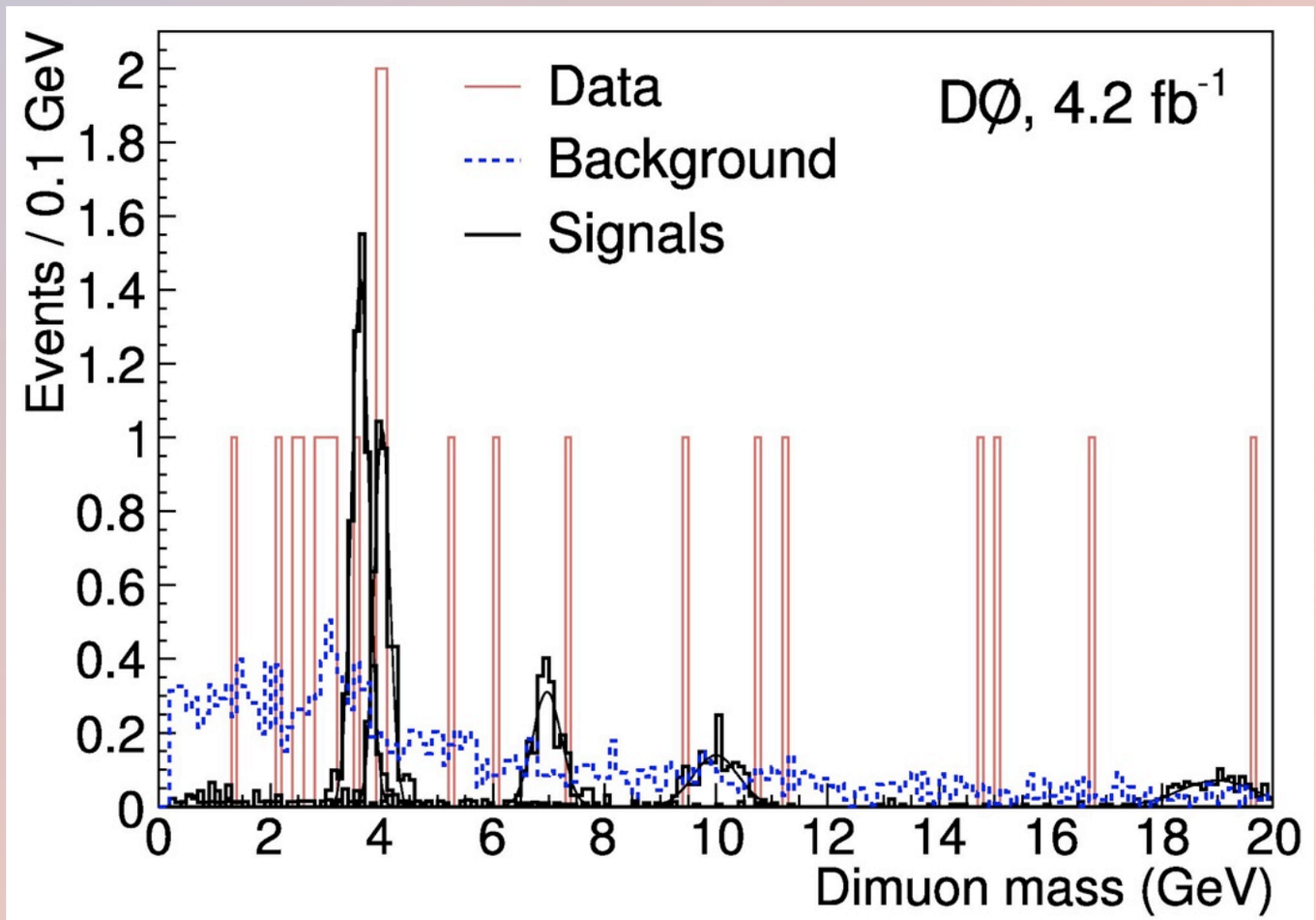


FIG. 2: The dimuon invariant mass for events passing all selections in data, background, and $2\mu 2\tau$ signals for M_a = 3.6, 4, 7, 10, and 19 GeV. $\sigma(p\bar{p}\rightarrow h+X)$=1.9 pb is assumed, BR($h\rightarrow aa$)=1, and M_h=100 GeV.

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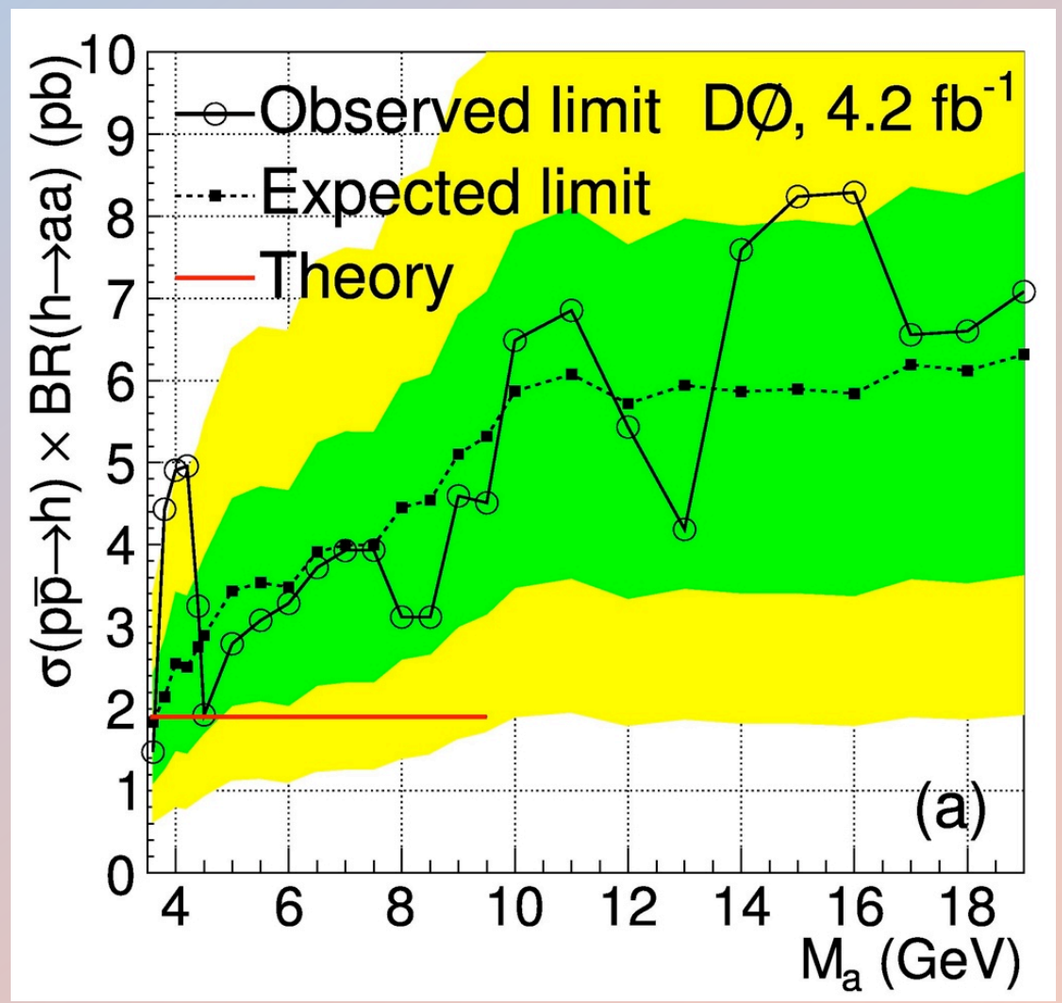


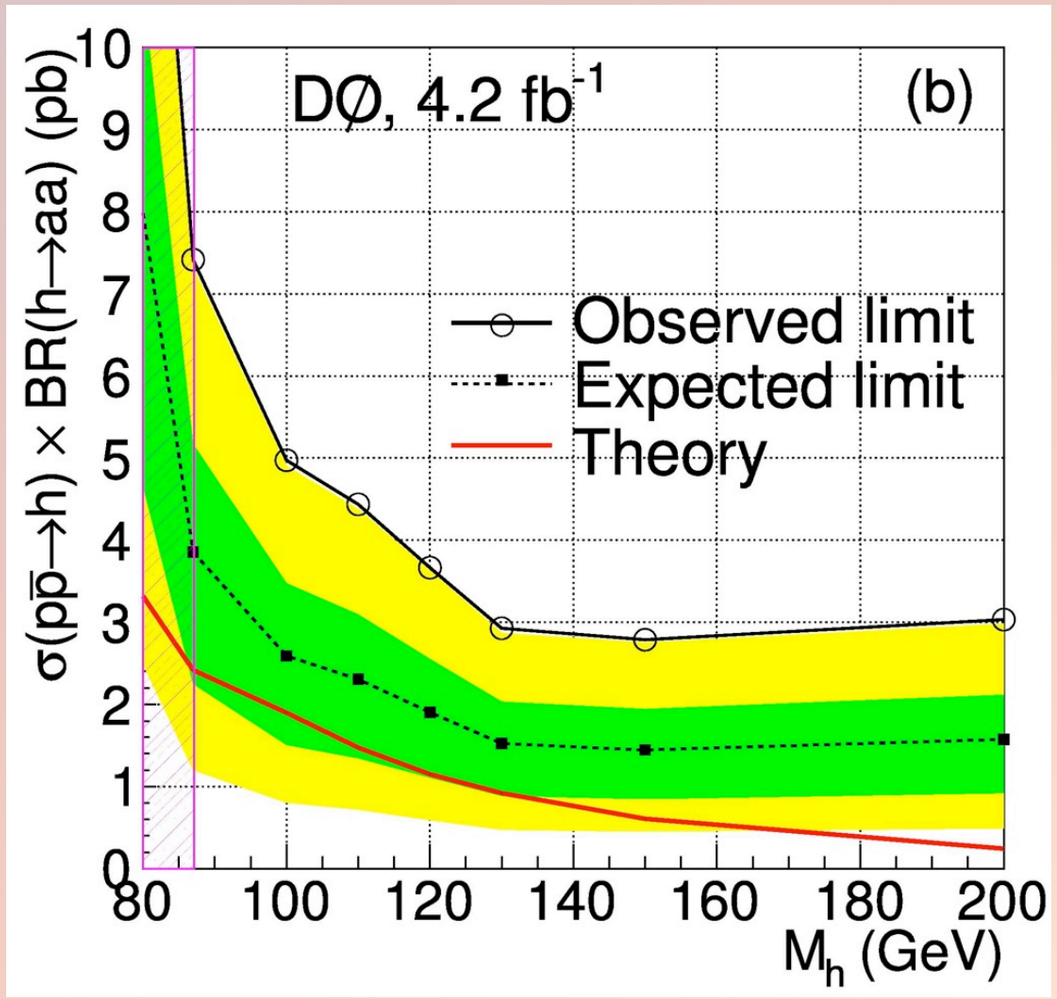
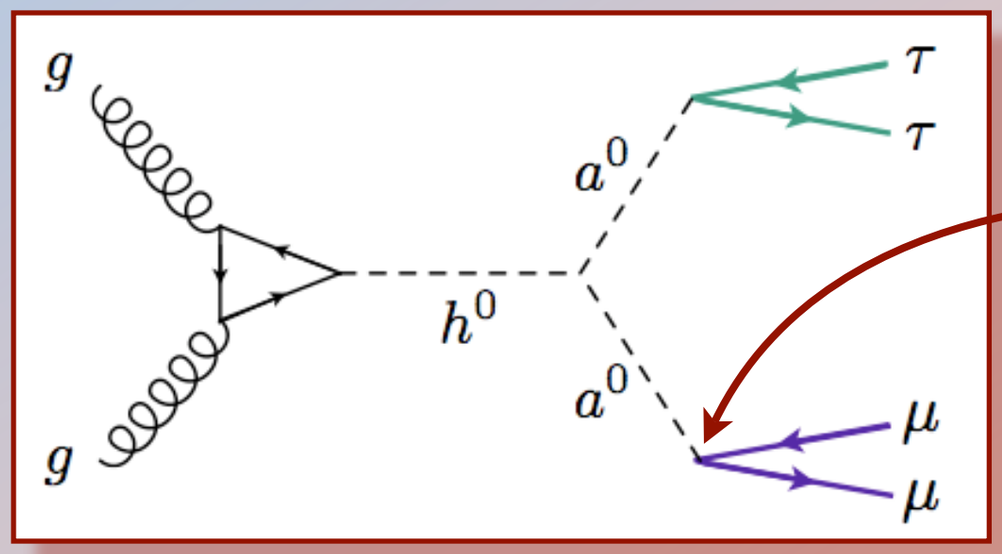


FIG. 3: The expected and observed limits and ±1 s.d. and ±2 s.d. expected limit bands for $\sigma(p\bar{p}\rightarrow h+X)\times \mathrm{BR}(h\rightarrow aa)$, for (a) M_h=100 GeV and (b) M_a=4 GeV. The signal for $\mathrm{BR}(h\rightarrow aa)$=1 is shown by the solid line. The region M_h<86 GeV is excluded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

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

DØ, arXiv:0905.3381 [hep-ex]



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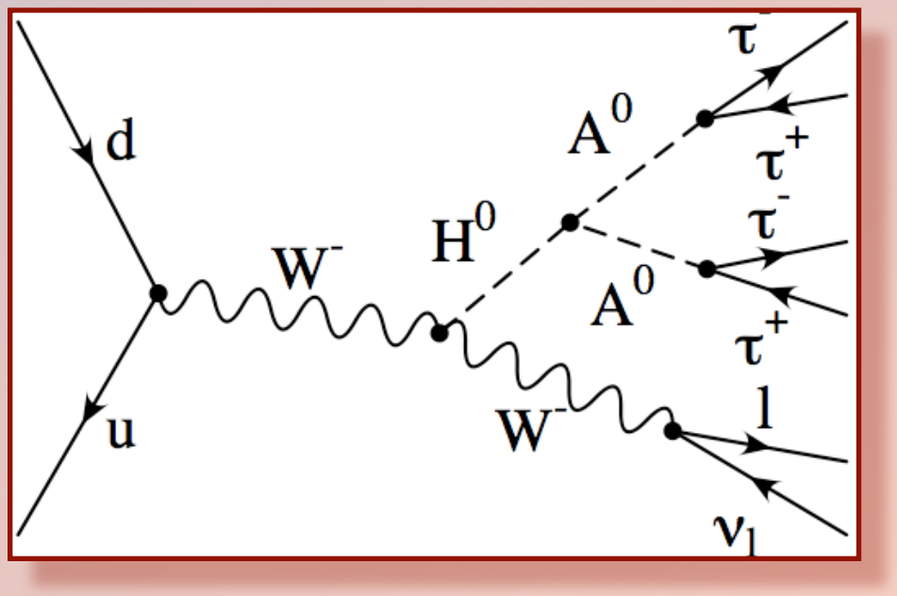
smaller but cleaner!

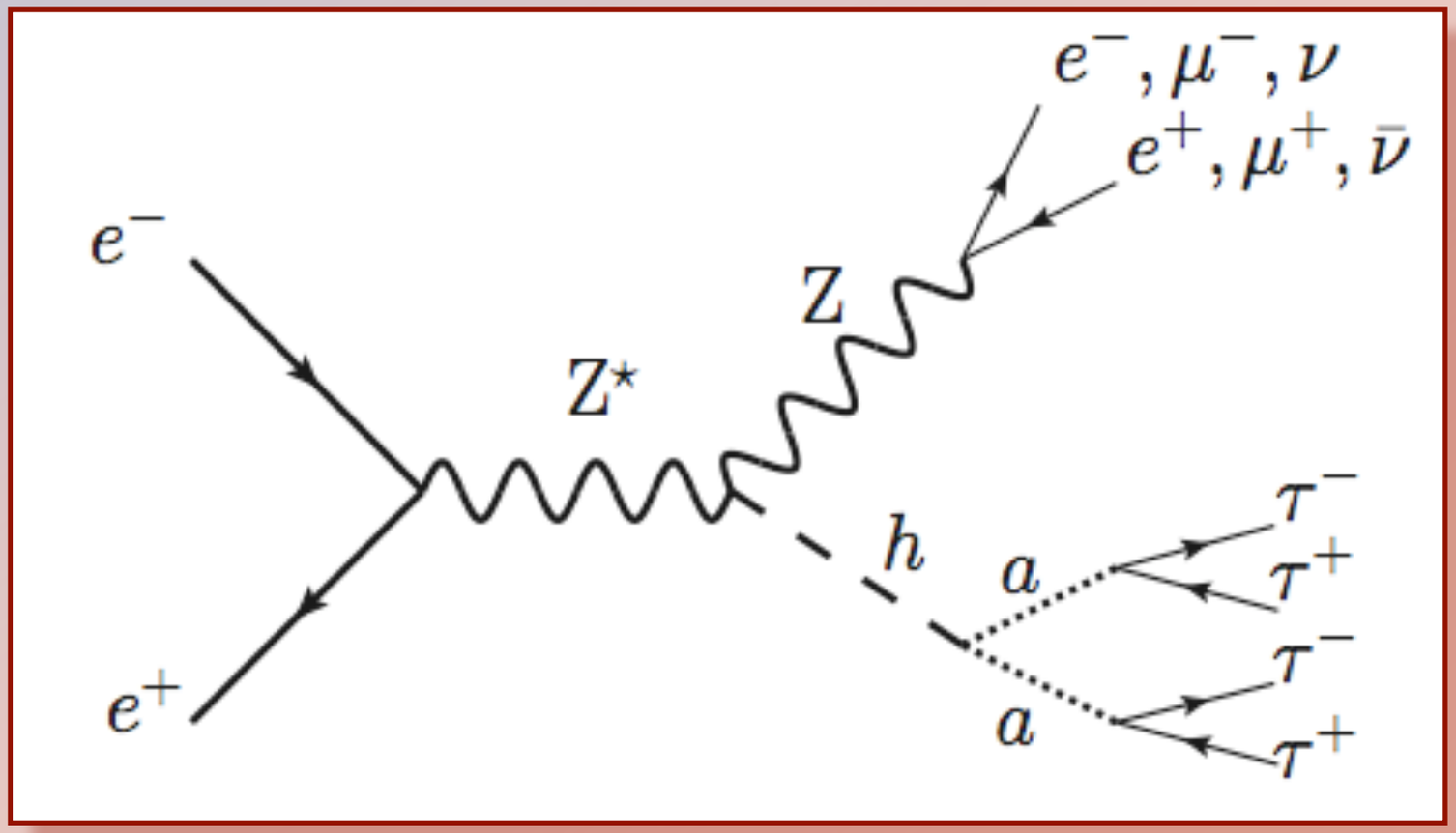
should be relatively easy at the LHC
~500 events with $1\,\mathrm{fb}^{-1}$

S. Wilbur, CDF, in progress



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

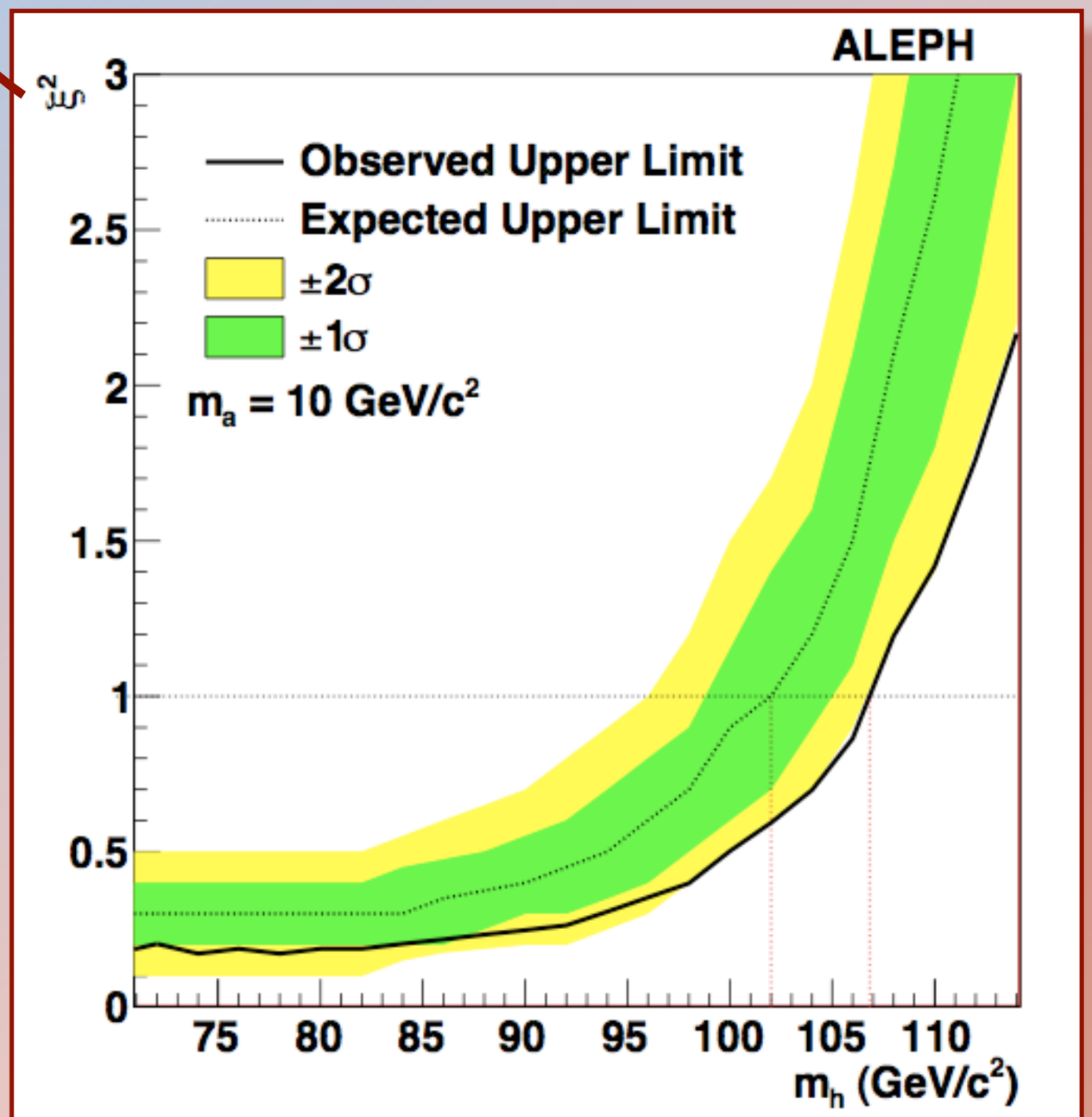
K. Cranmer, Aleph, arXiv:1003.0705 [hep-ex]

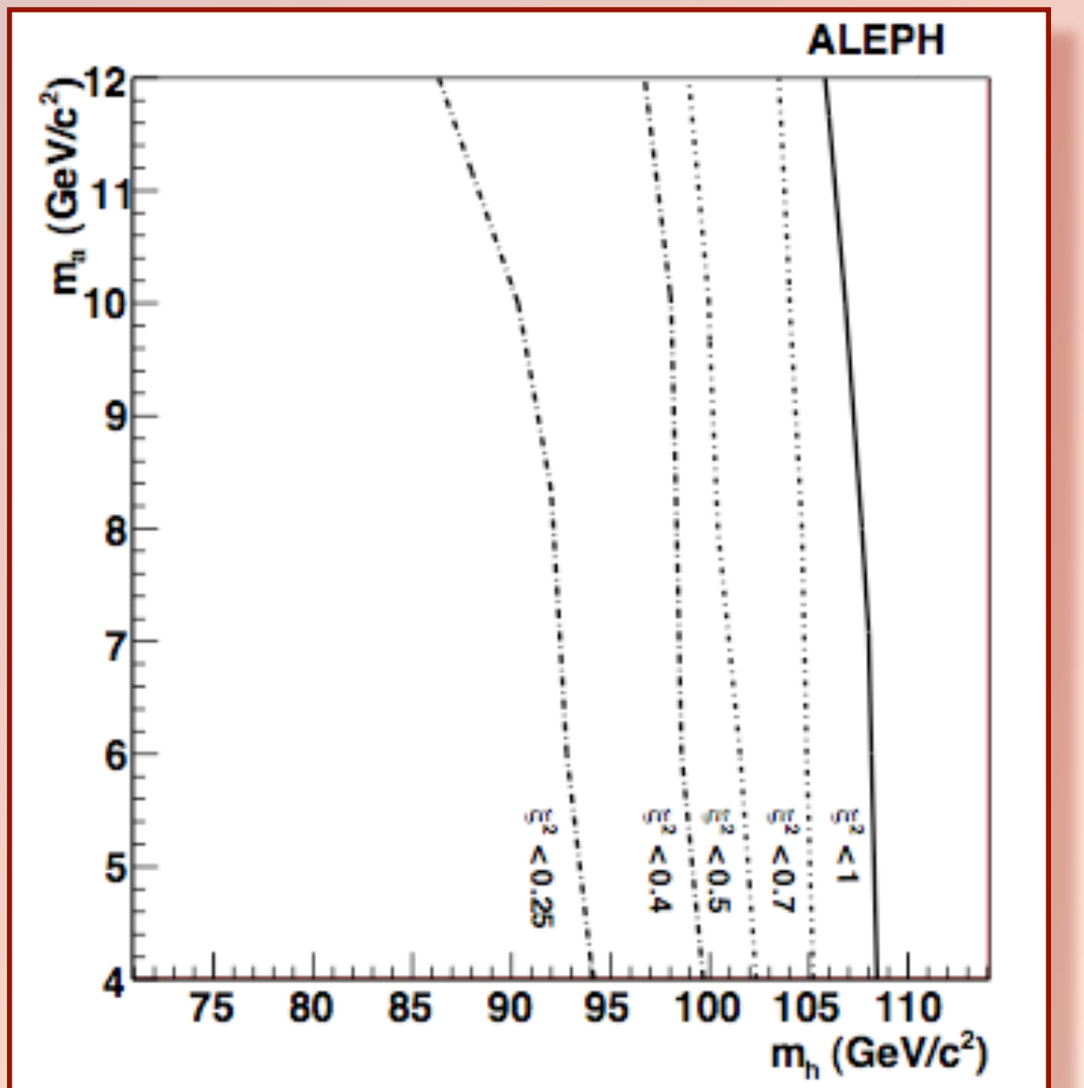


Aleph search for $h \longrightarrow aa \longrightarrow 4\tau$

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

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

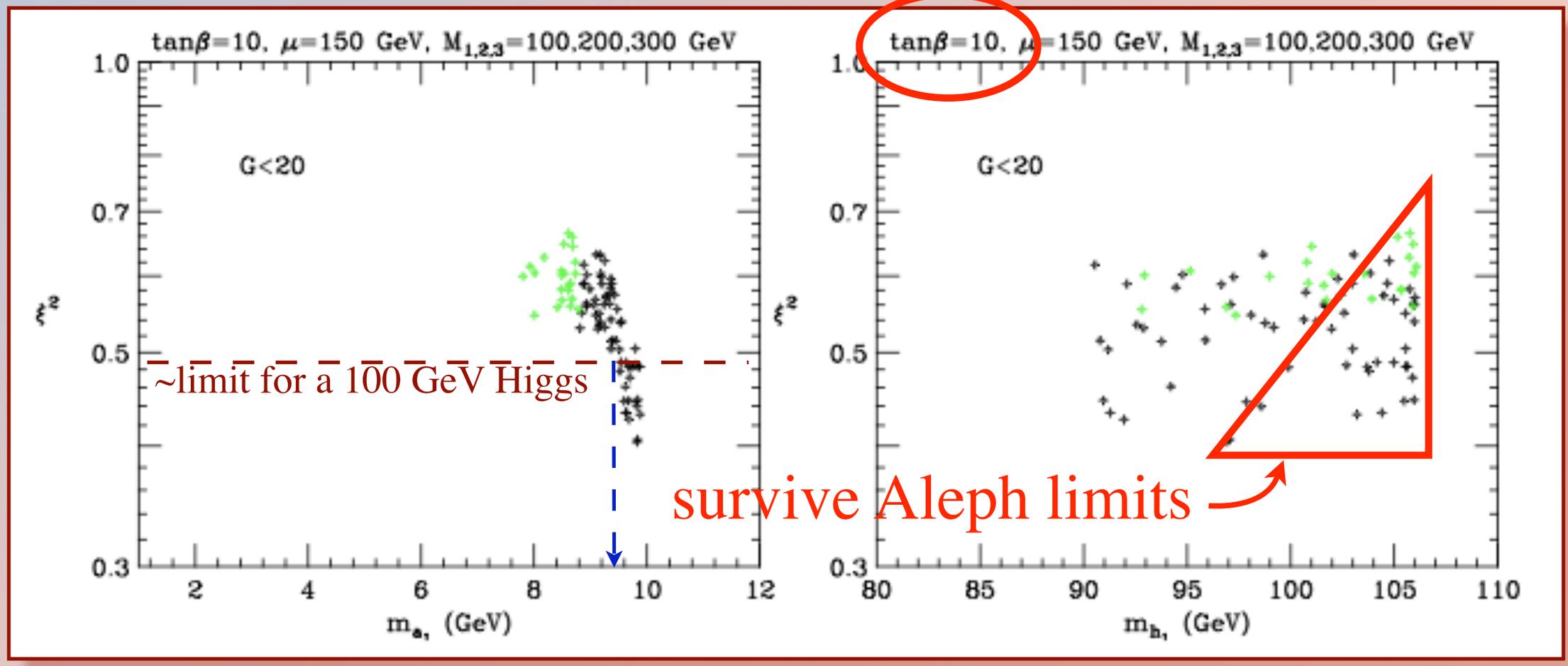




Aleph search for $h \longrightarrow aa \longrightarrow 4\tau$

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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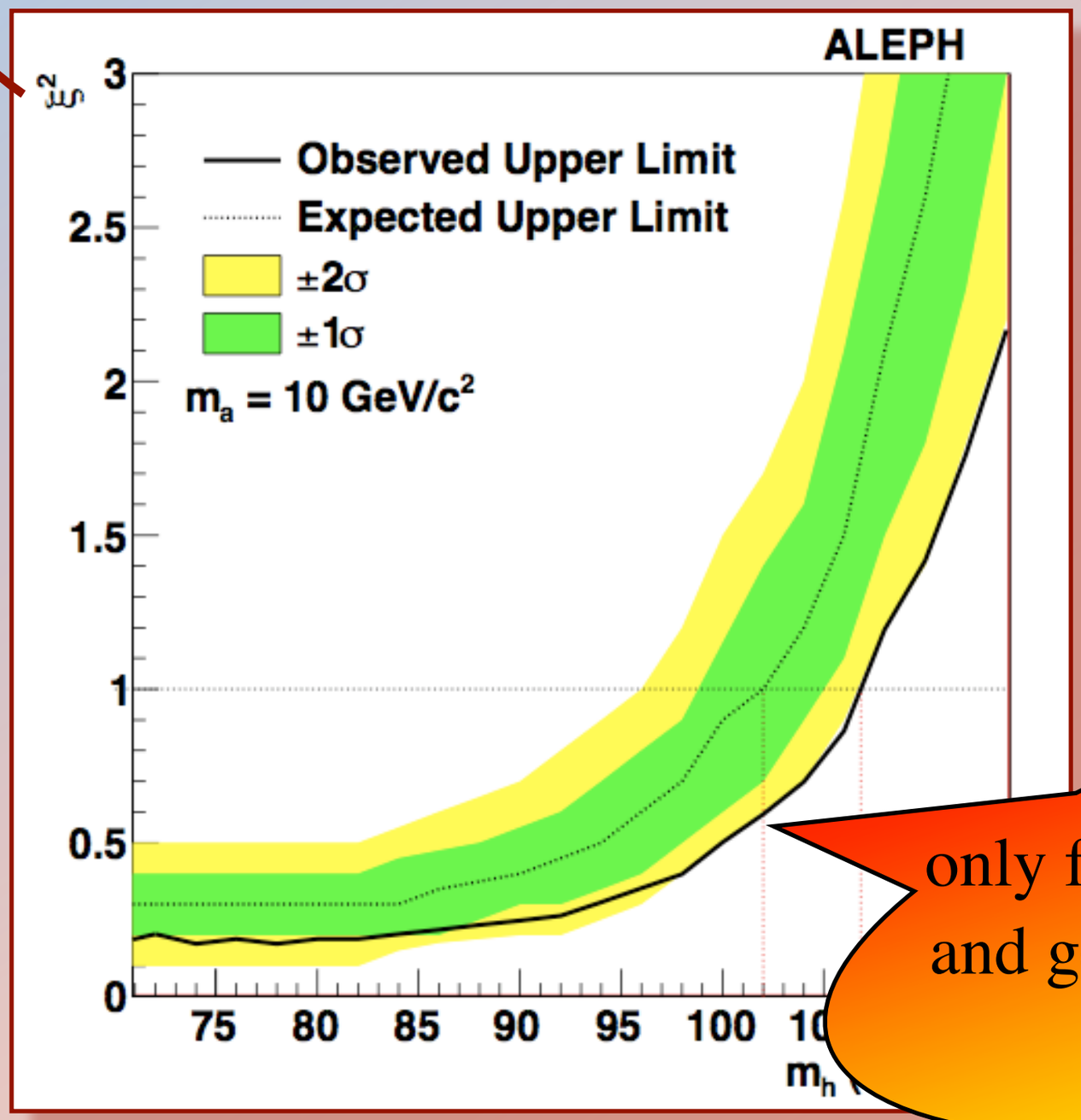
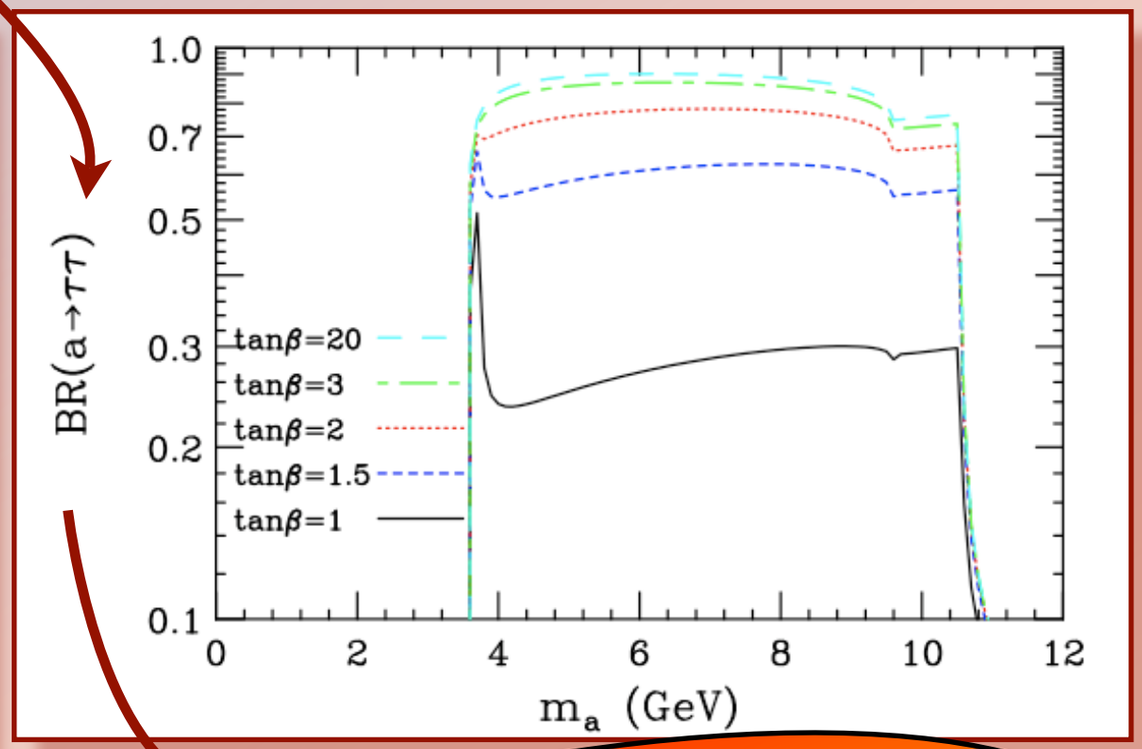


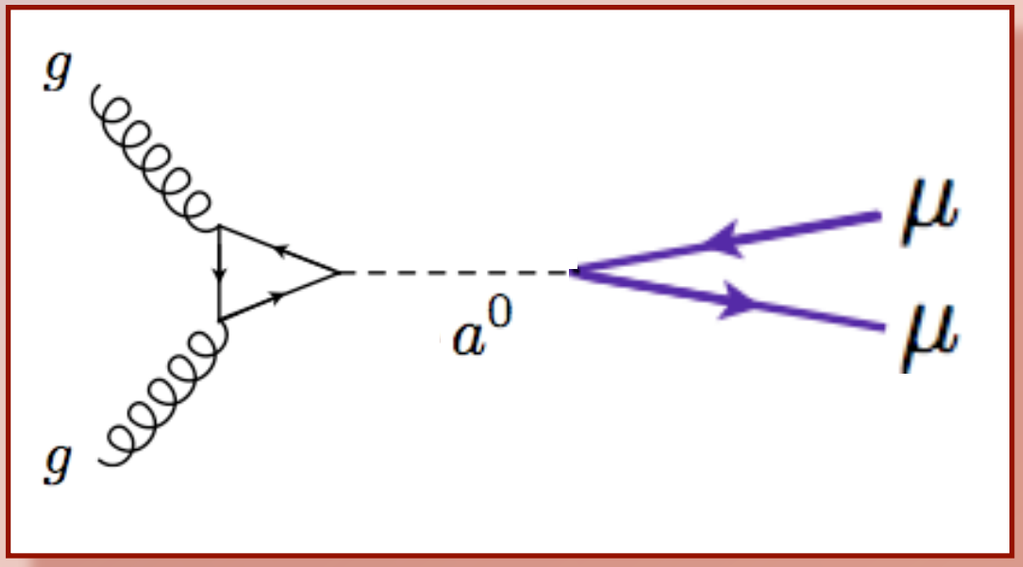


Limits allow
$m_h \simeq 100$ GeV
only for $m_a \simeq 10$ GeV when $\tan\beta > 3$
and generically for $\tan\beta \lesssim 2$

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:

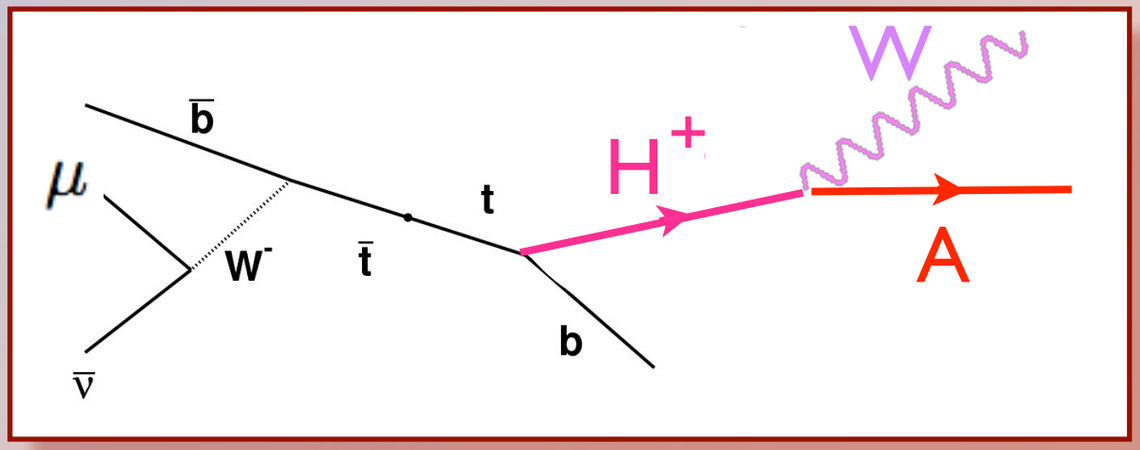
integrated luminosity (fb^{-1}) needed for 5σ:

Case
ATLAS LHC7
ATLAS LHC10
ATLAS LHC14

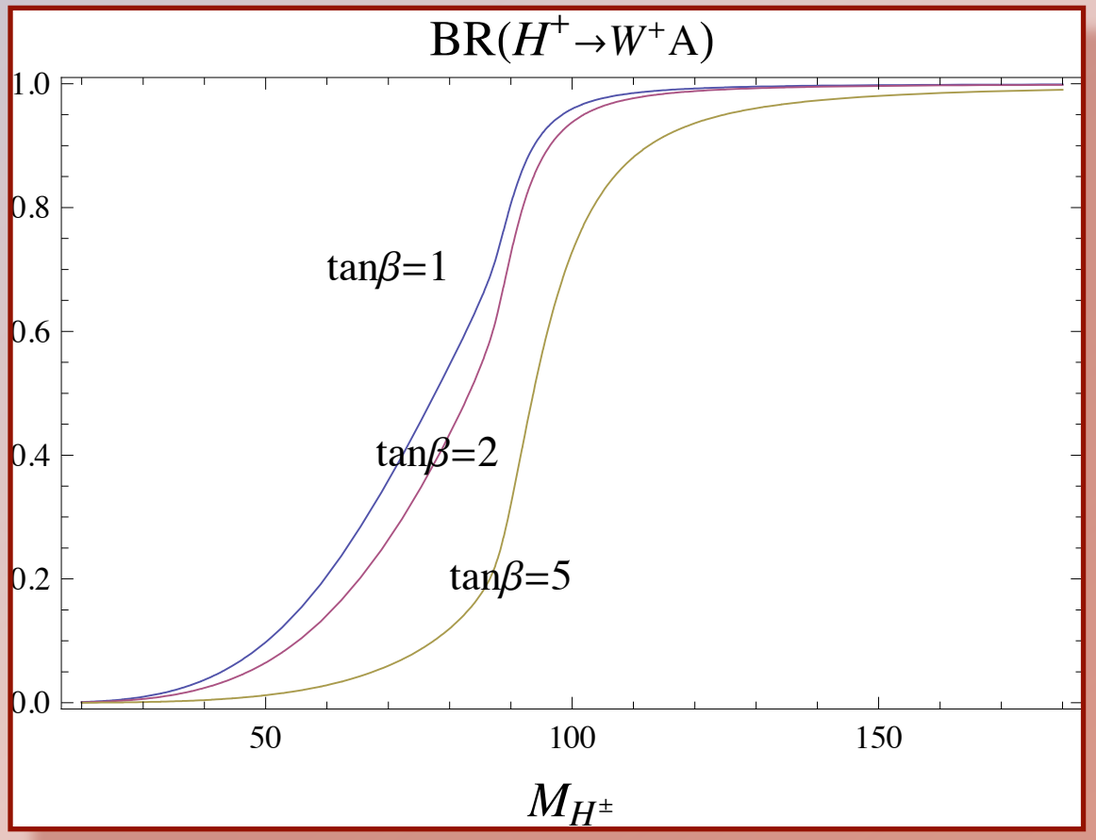
talk of J. Gunion (tomorrow)

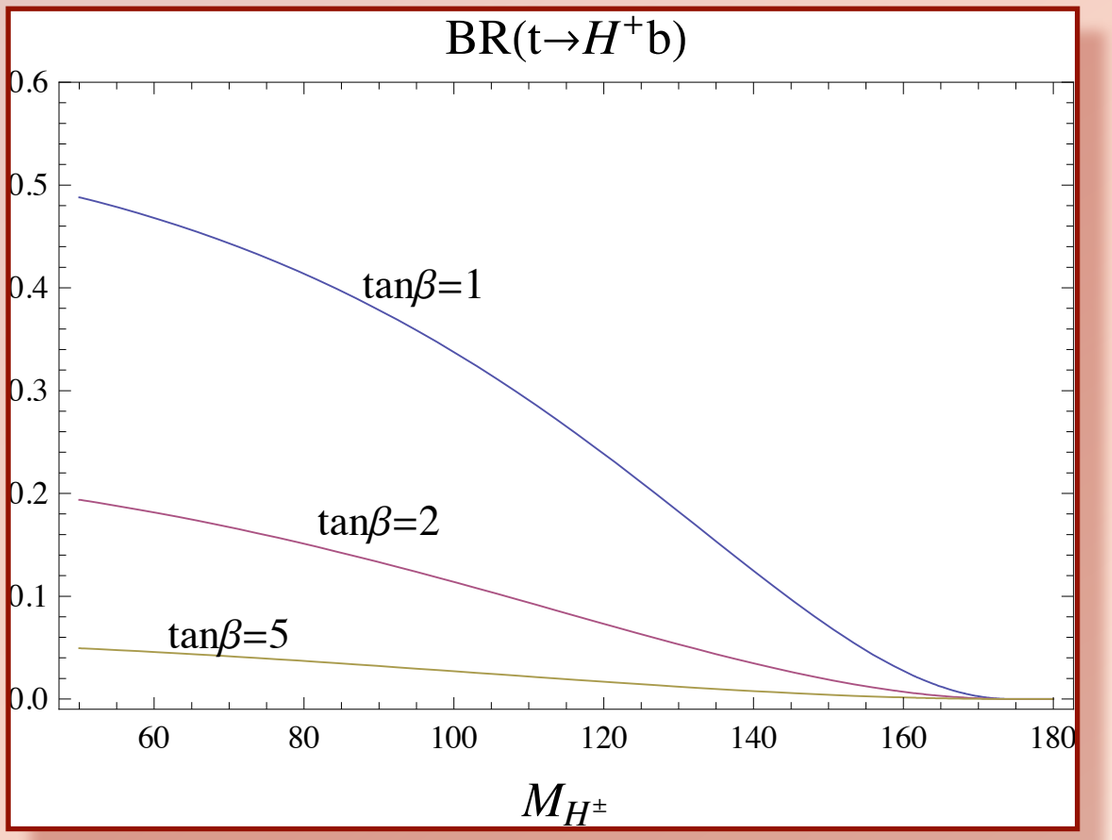
Charged Higgs in Top quark decays

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

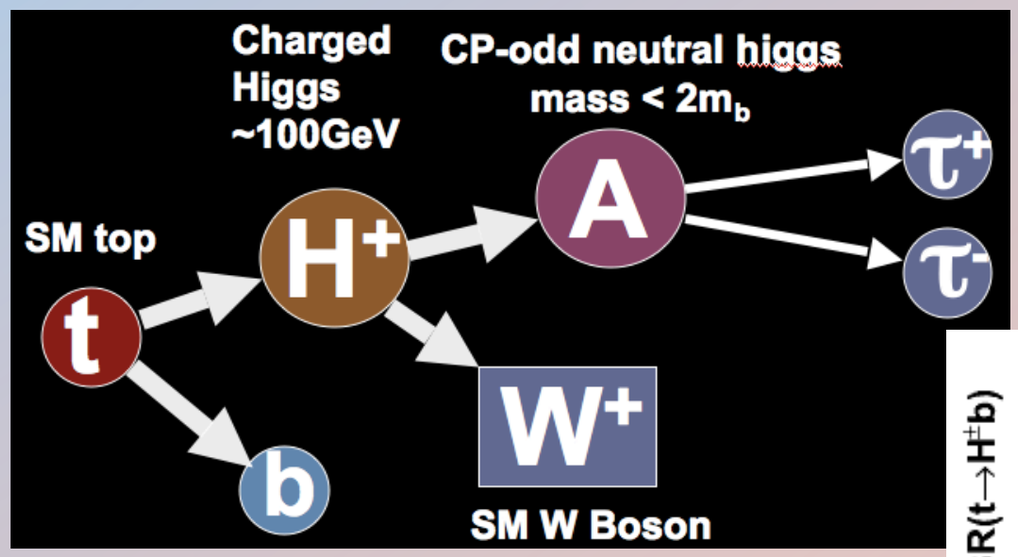


In MSSM:





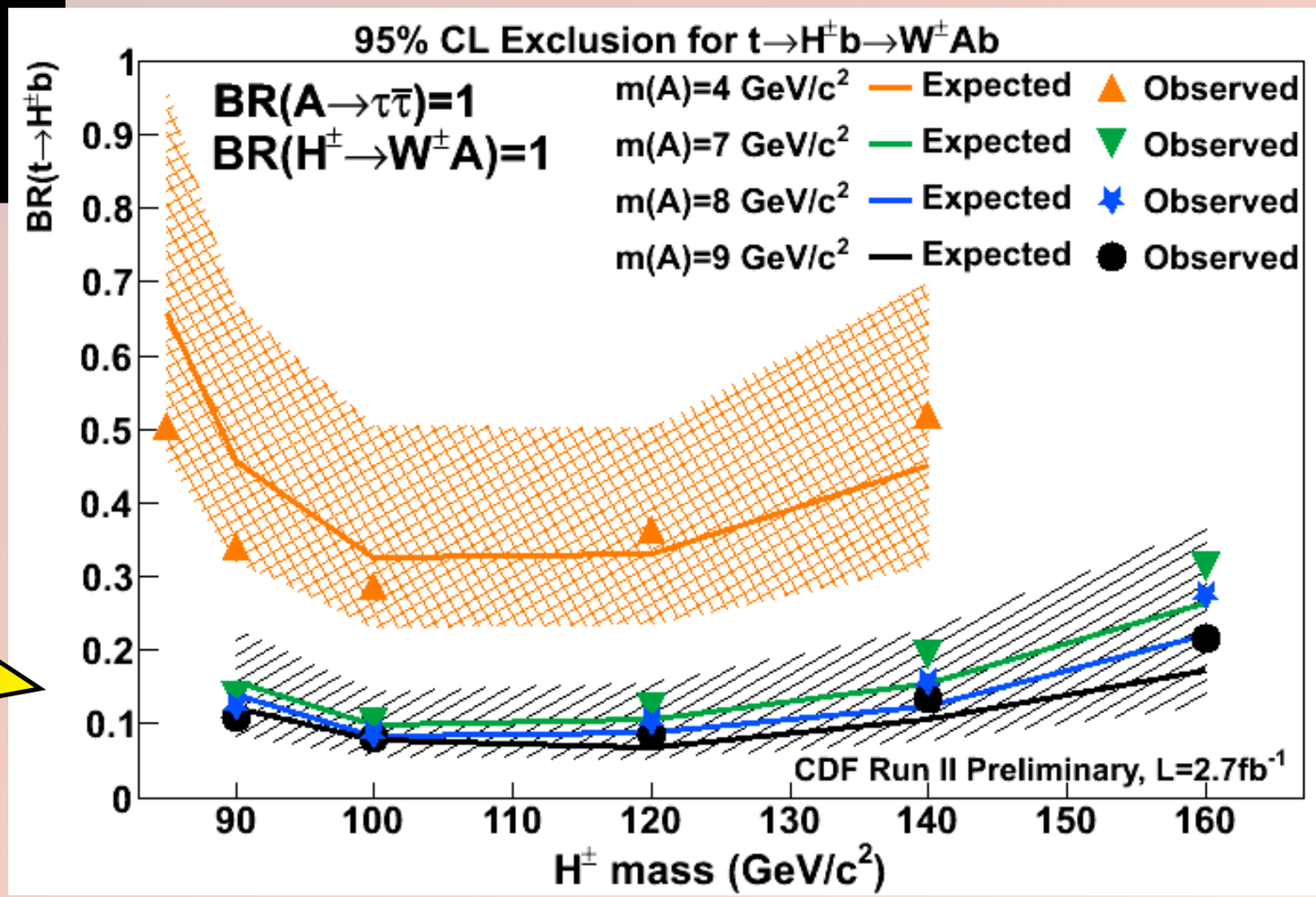
CDF search for charged Higgs



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

Limits allow

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



Charged Higgs at the LHC

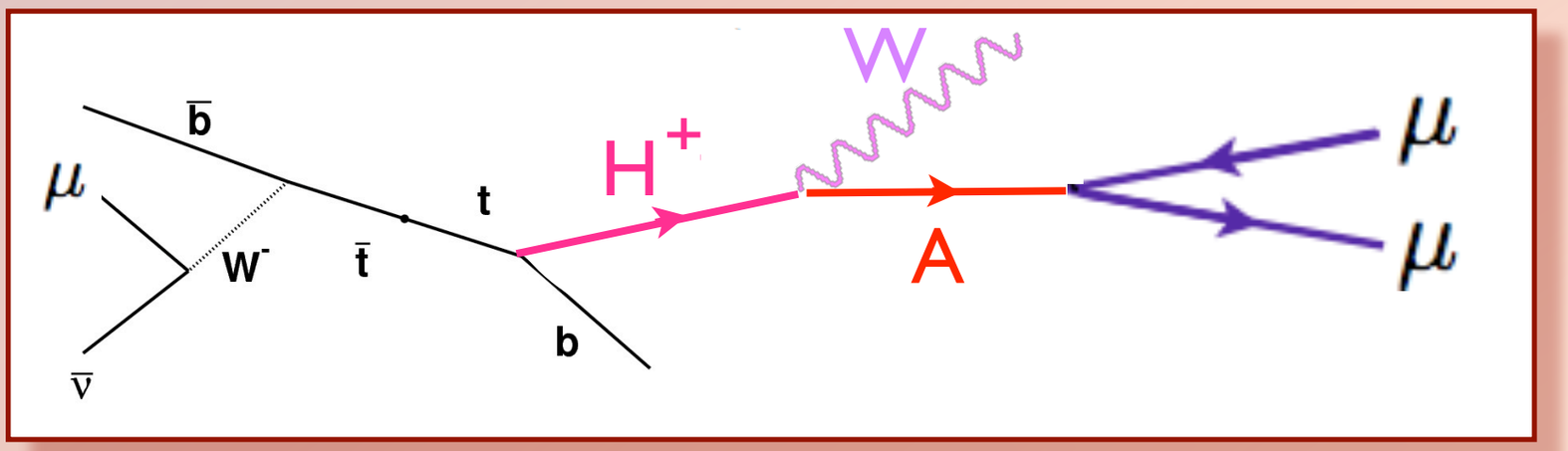
R.D., E. Lunghi and A. Raval, in progress

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

- one of the two Ws: $W \to \mu\nu$ 20%

- CP-odd Higgs: $a \to \mu\mu$ 1/250

- for $Br(t \to H^+ b) = 10\%$ we have 650 3-muon events



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

it is going to be a lot of fun...