Non-Standard Higgs Decays

motivation and experimental limits

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    $\longrightarrow$ non-standard Higgs decays
- A simple example
- EXPERIMENTAL LIMITS
- Conclusions

Higgs Mass in MSSM

$$m_h^2 \simeq M_Z^2 \cos^2 2\beta + \frac{3G_F m_t^4}{\sqrt{2}\pi^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{A_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{A_t^2}{12m_{\tilde{t}}^2}\right)\right]$$

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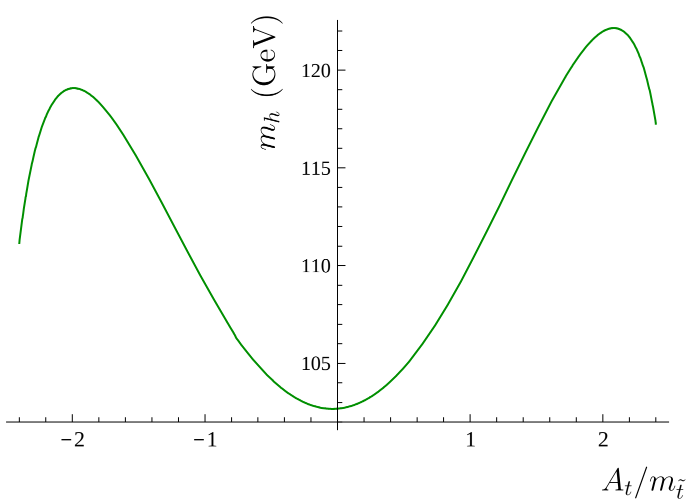
Effect of large mixing:

[FeynHiggs-2.5.1: $\tan\beta = 10$, $m_{\tilde{t}} = 400$ GeV]



m_h maximized for $A_t/m_{\tilde{t}} \simeq \pm 2$

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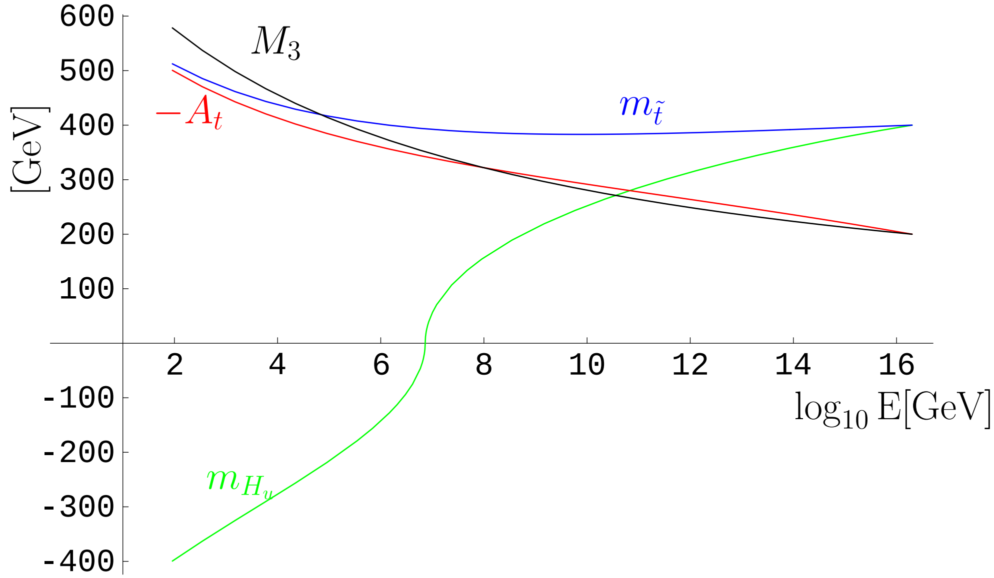
Typical mixing $|A_t/m_{\tilde t}| \lesssim 1$:

$$m_{\tilde t}^2(M_Z) \simeq 5.0 M_3^2(M_G) + 0.6 m_{\tilde t}^2(M_G)$$
$$A_t(M_Z) \simeq -2.3 M_3(M_G) + 0.2 A_t(M_G)$$



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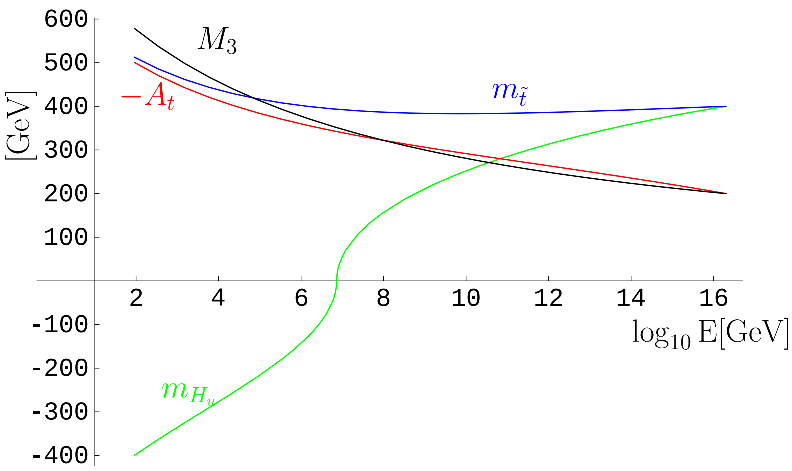
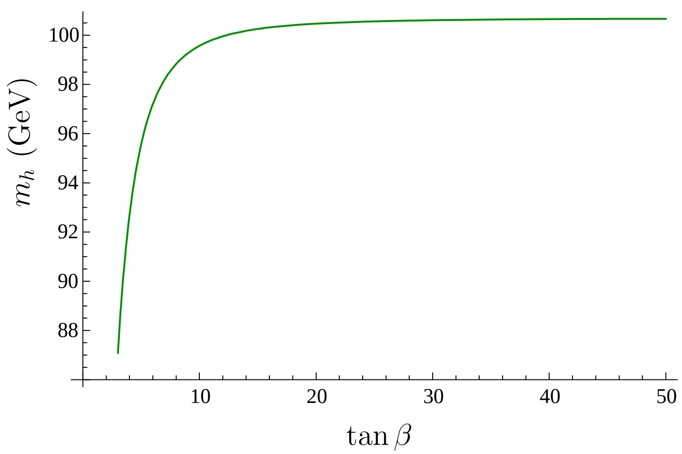
Typical mixing $|A_t/m_{\tilde{t}}| \simeq 1$



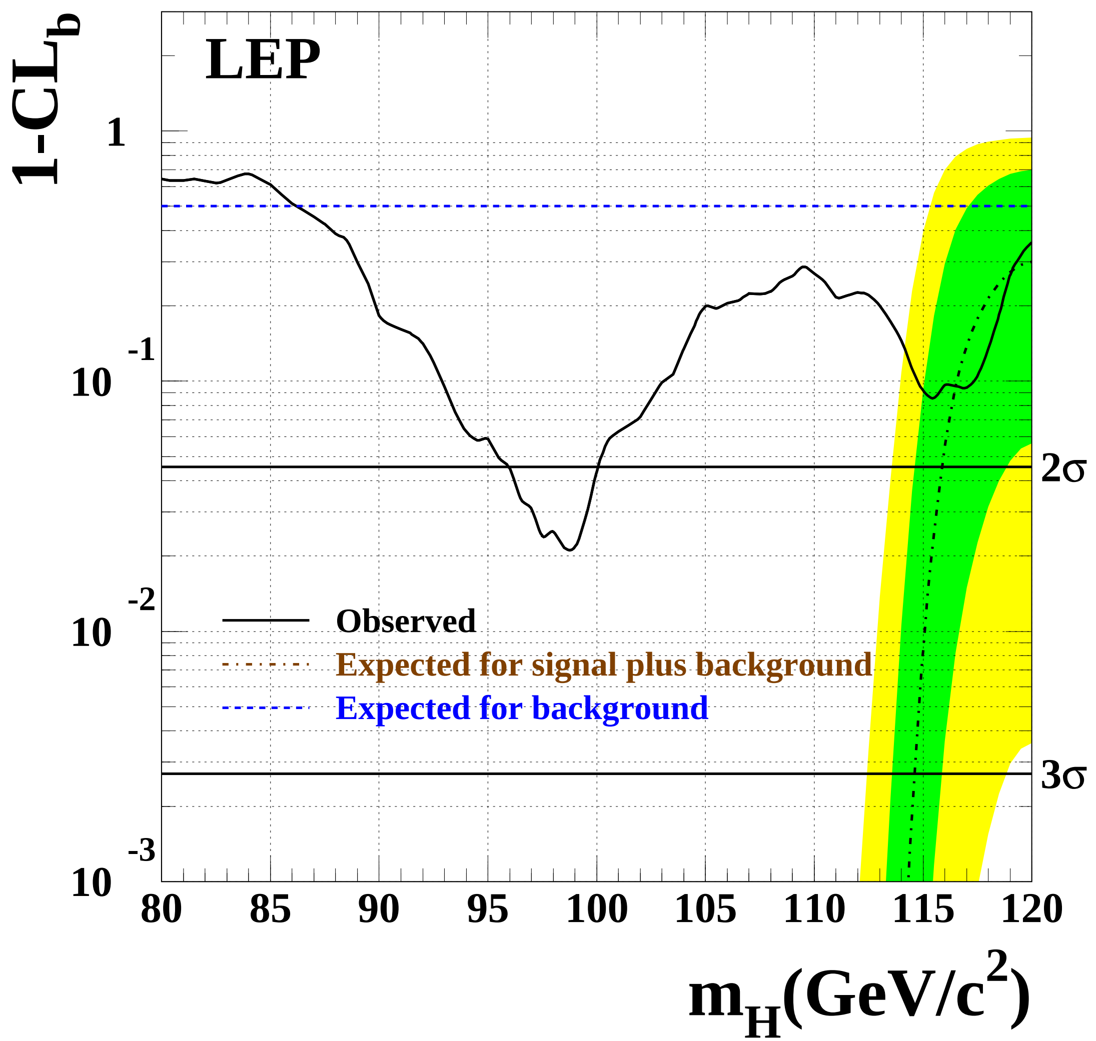
Typical Higgs mass



[FeynHiggs-2.5.1: $M_{SUSY} = m_A = \mu = 200$ GeV]

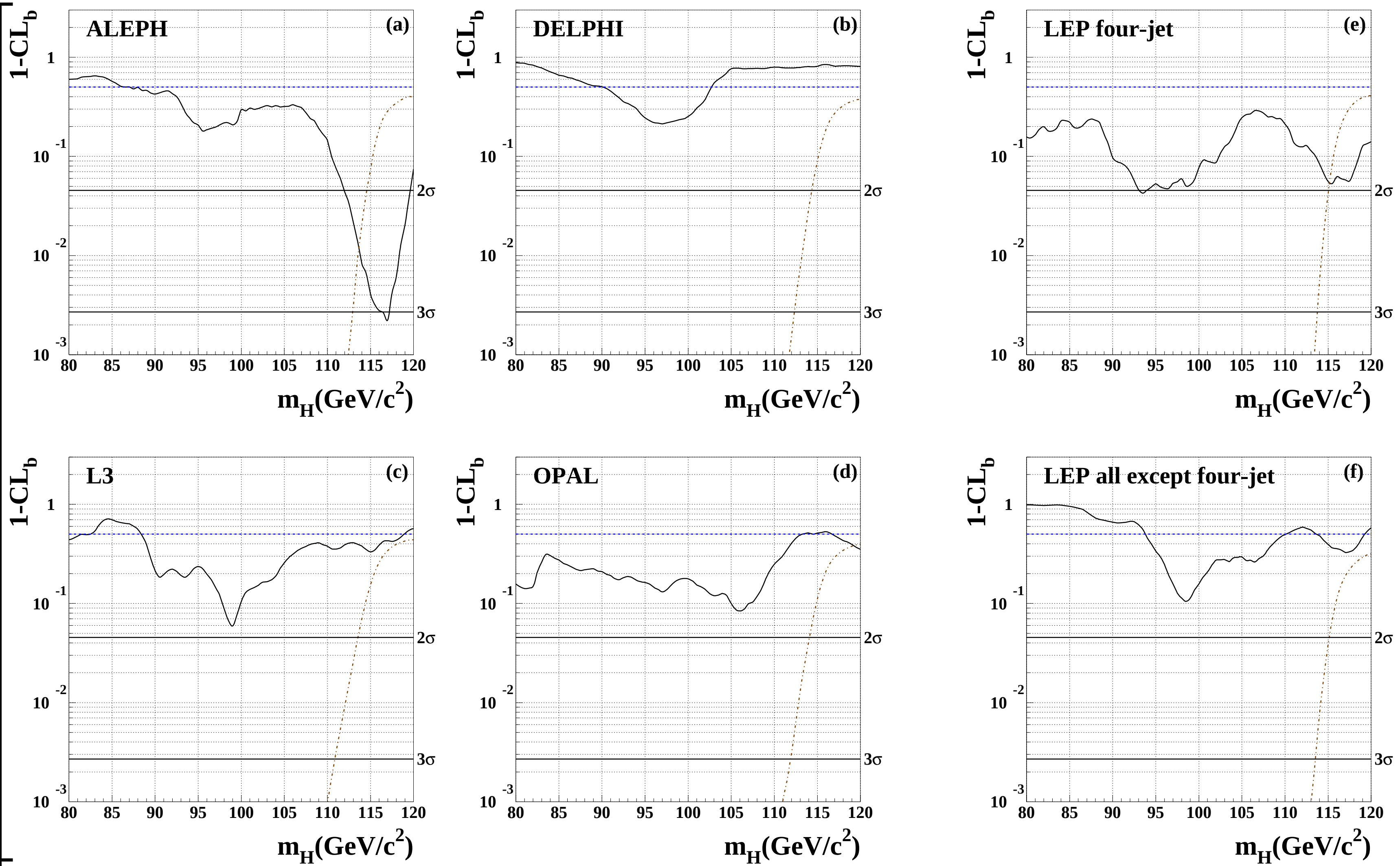
Search for the SM Higgs at LEP

LHWG-2003-011

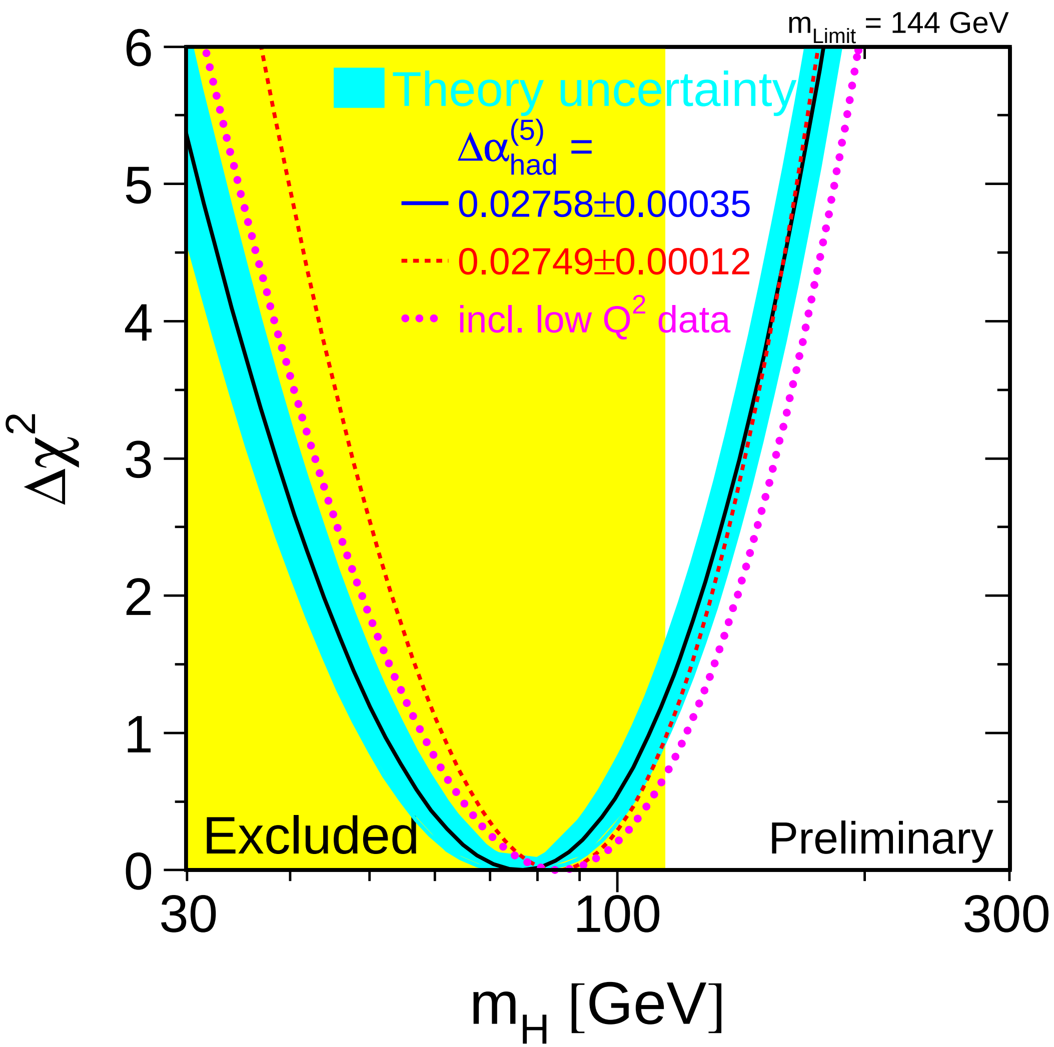


Search for the SM Higgs at LEP

LHWG-2003-011



Precision electroweak data



EWWG 2007

$m_h = 76^{+33}_{-24}$ GeV

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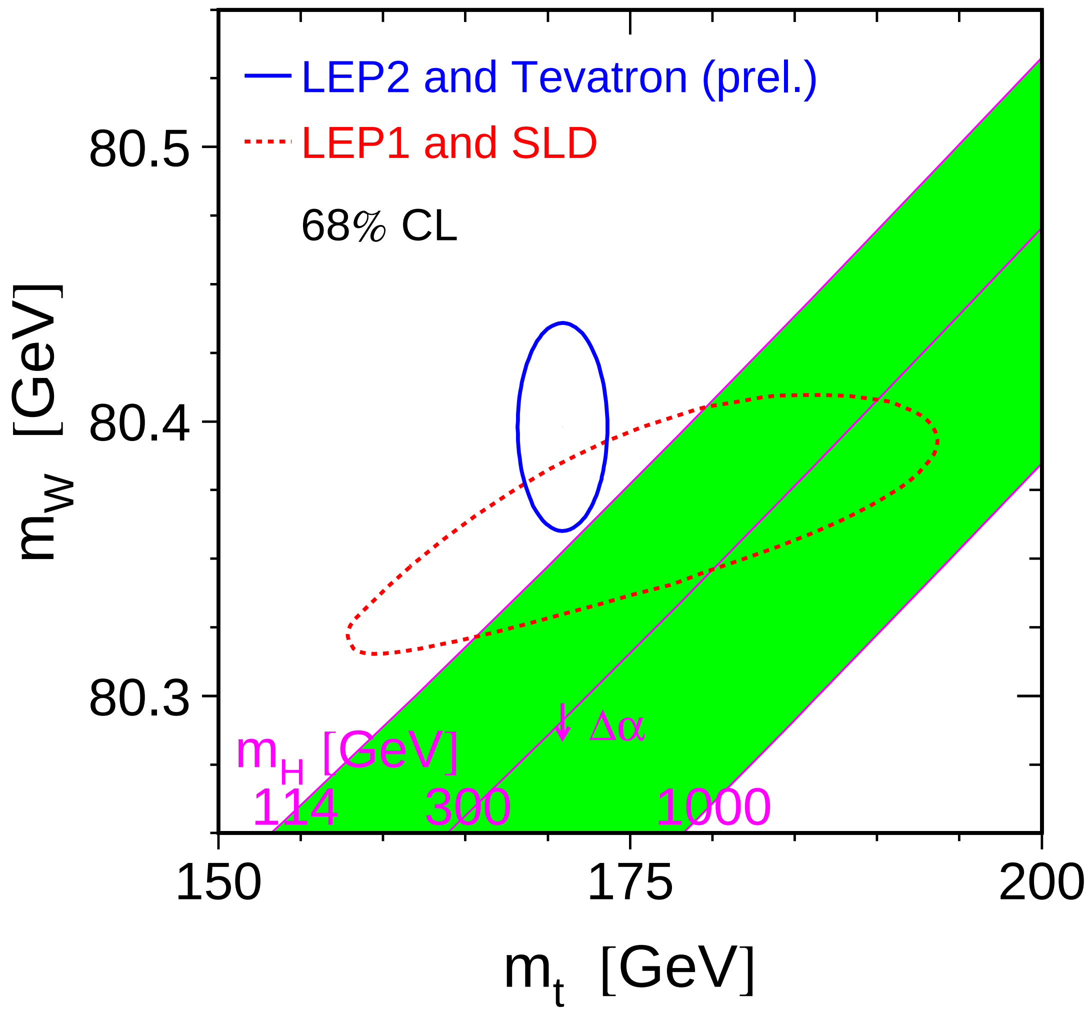
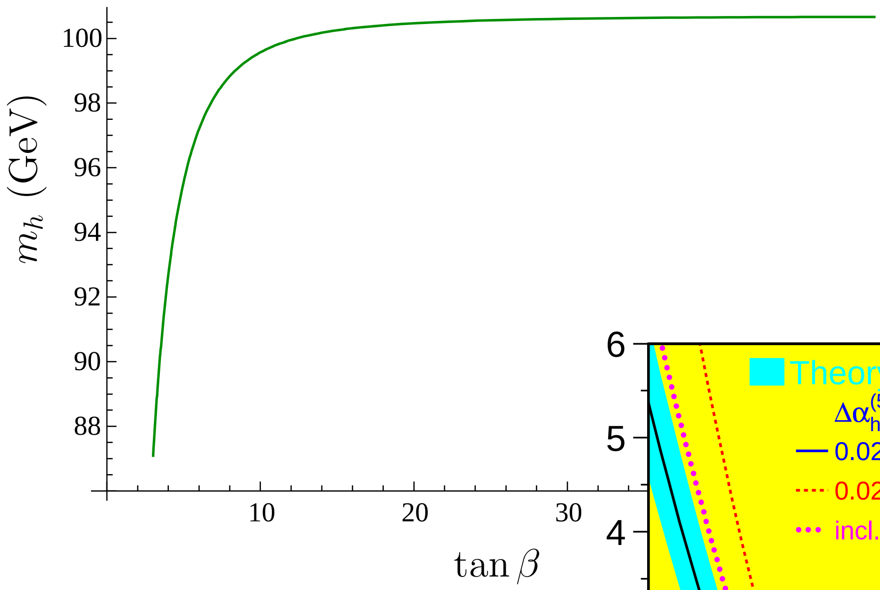


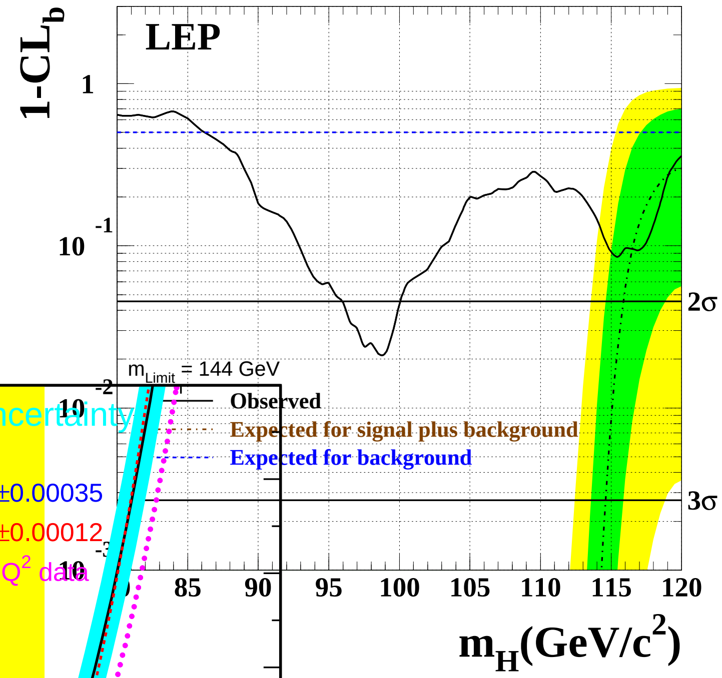
EWWG 2007

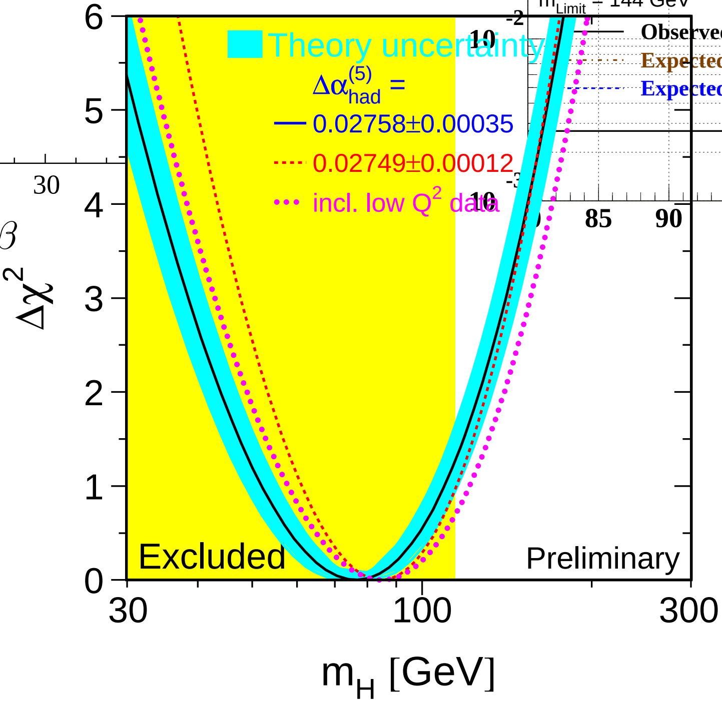
$m_h = 76^{+33}_{-24}$ GeV

LEP Puzzle

Typical Higgs mass: $A_t/m_{\tilde{t}} = 1$, $m_{\tilde{t}} = 180$ GeV







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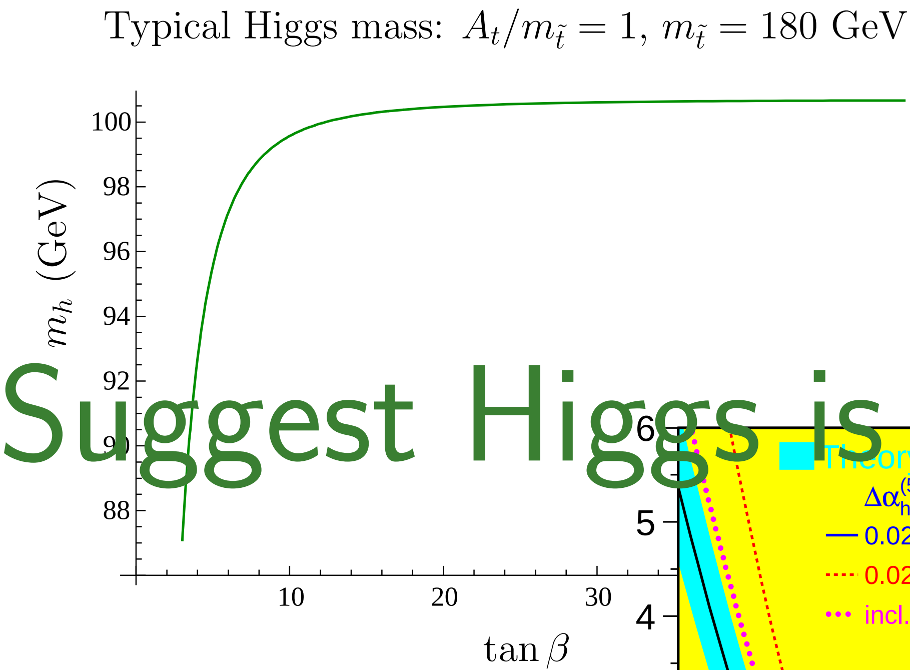
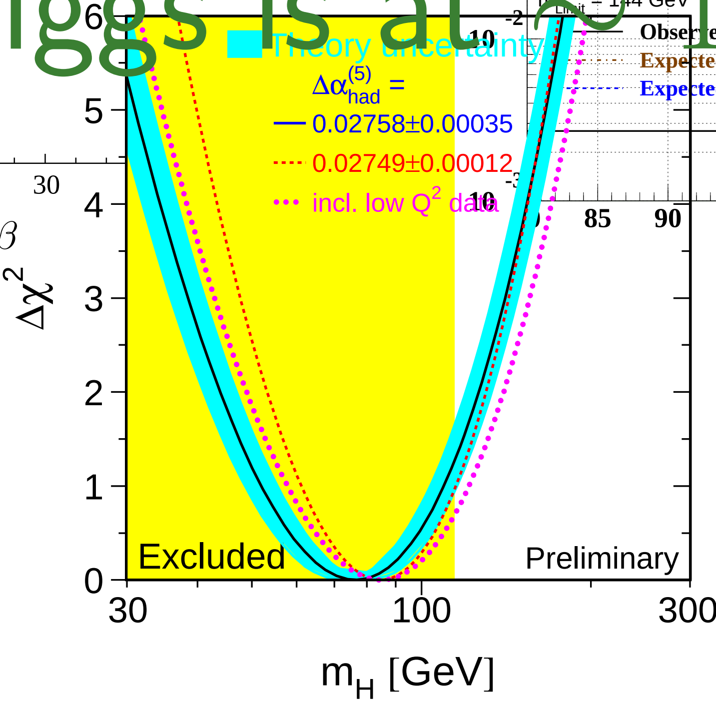
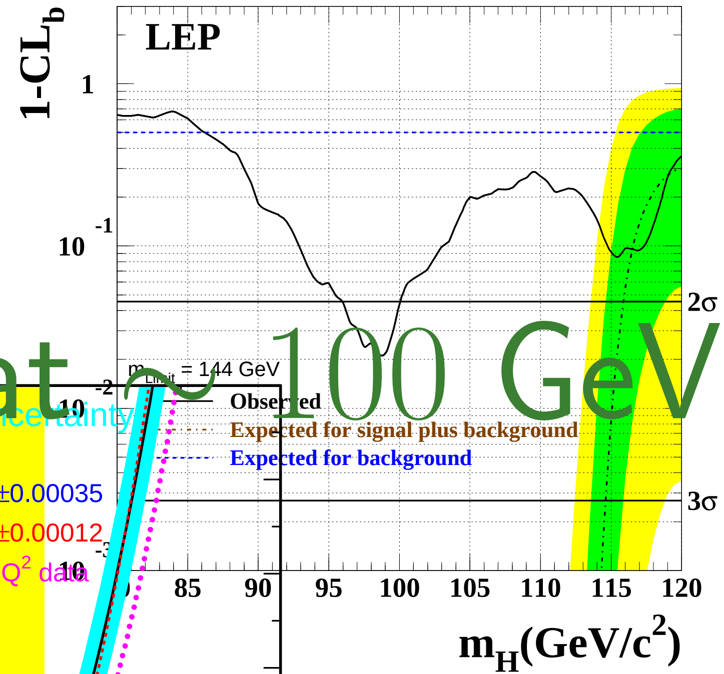
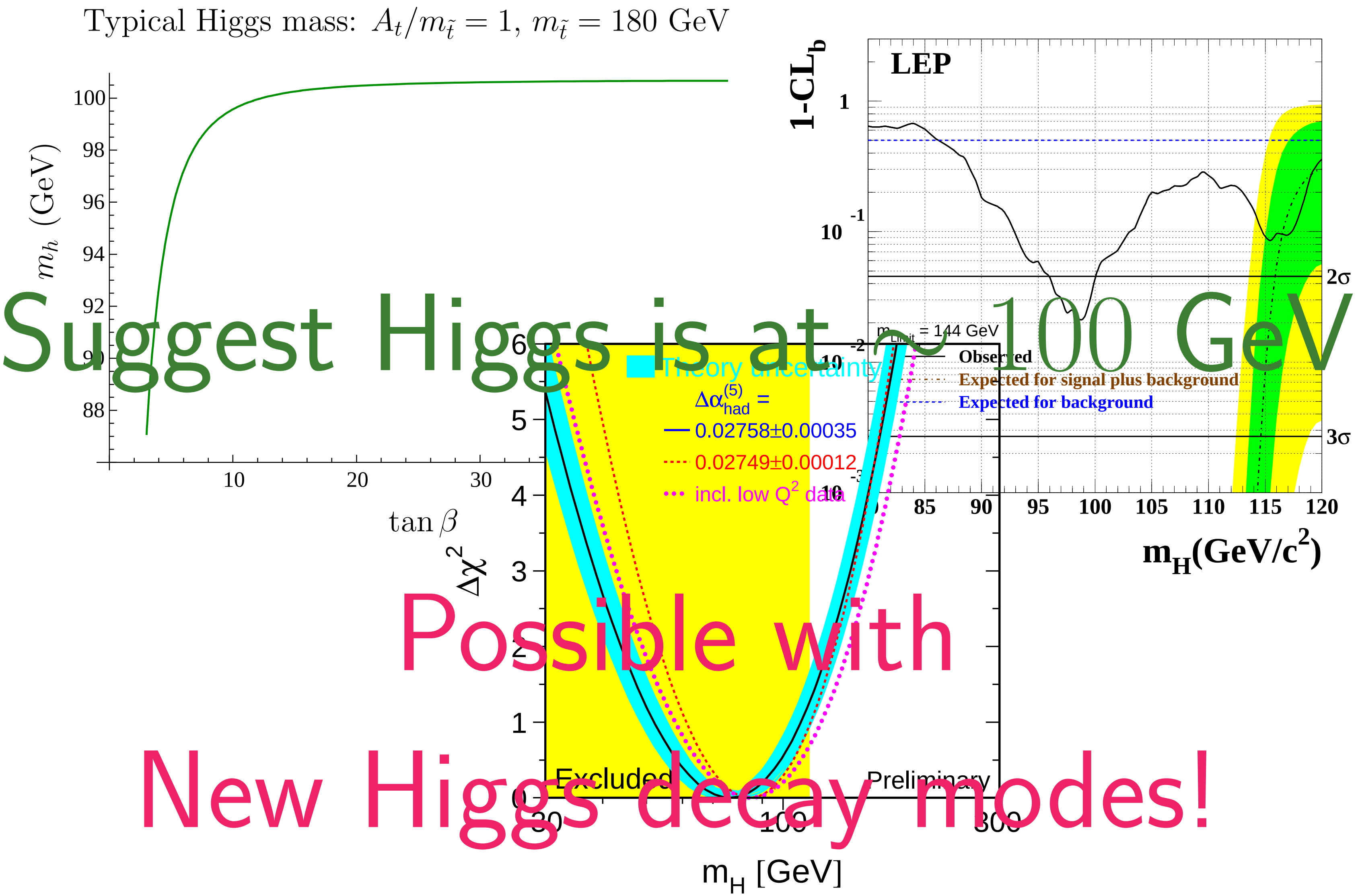






Suggest Higgs is at ~ 100 GeV

LEP Puzzle



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Possible with

New Higgs decay modes!

Theoretical hints for new decay modes:

- small $hb\bar{b}$ coupling

  it doesn't take a large Higgs coupling to a new particle for the decay width to these new particles to dominate over the decay width to SM particles ($\Gamma \simeq 2.3$ MeV or $10^{-5}\,m_h$ for $m_h \sim 100$ GeV)

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- the μ problem of the MSSM

$$W = \mu \widehat{H}_u \widehat{H}_d$$

  $\mu \sim M_{SUSY}$ - problematic
  $\widehat{H}_u \widehat{H}_d$ is a SM singlet term, can couple to other singlet terms even at the renormalizable level - asking for extension of the Higgs sector, e.g.

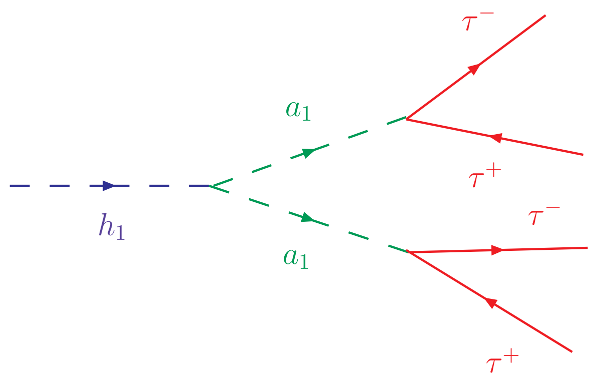
$$W = \lambda\, \widehat{S} \widehat{H}_u \widehat{H}_d, \quad \mu_{eff} = \lambda s$$

Example: extra light scalar, e.g. NMSSM

LEP puzzle solved in models with non-standard Higgs decays, e.g.:

$$h_1 \to a_1 a_1 \to 4\tau, \quad 4j, \quad \tilde{4}g, \quad \ldots$$

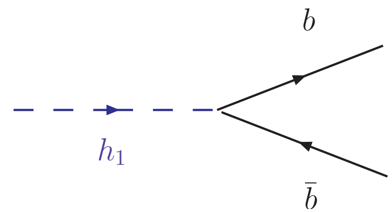
for $m_h \simeq 100$ GeV and $m_a \lesssim 10$ GeV there are no exp. limits!



90%

search at LEP - L3, C. Tully

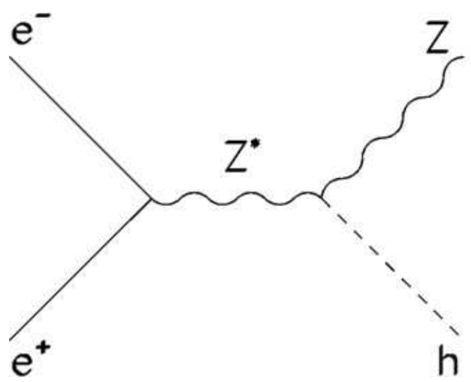
10%



can fully explain LEP Higgs excess at $m_h \simeq 100$ GeV

LEP limits on the Higgs boson

At LEP Higgs is dominantly produced in association with Z:



Searches constrain quantity:

$$\xi^2_{h\to X} = \frac{g^2_{ZZh}}{g^2_{ZZh_{SM}}} B(h \to X)$$

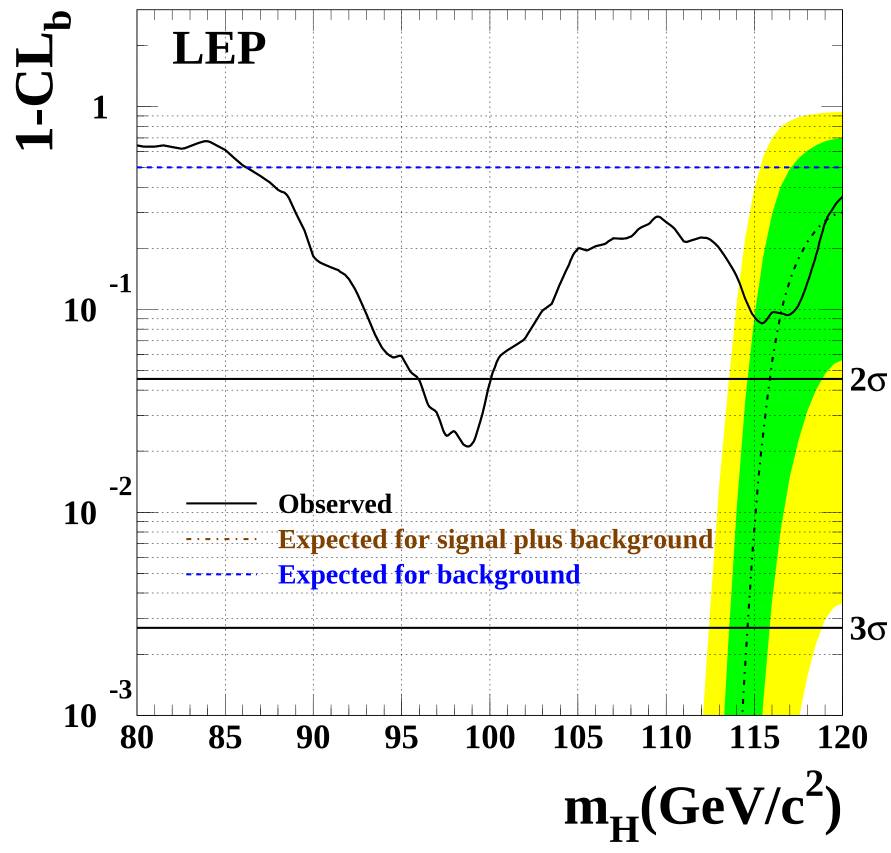
SM-like Higgs: $g^2_{ZZh}/g^2_{ZZh_{SM}} = 1$

Unless specified, the limits are 95% CL lower bounds assuming $\xi^2_{h\to X} = 1$

LEP limits on the Higgs boson

- Standard Model Higgs $m_h > 114.4$ GeV

$$h \to b\bar{b},\ \tau^+\tau^-$$



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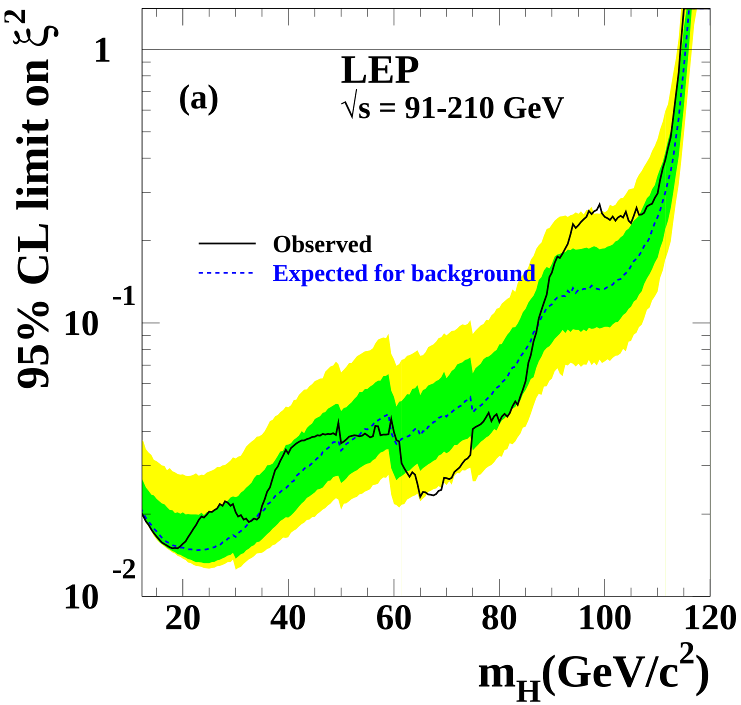
Higgs with reduced coupling to Z: $\xi^2 = g^2_{ZZh}/g^2_{ZZh_{SM}}$:



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$h \to 2$ SM particles $\quad m_h \gtrsim 114$ GeV!

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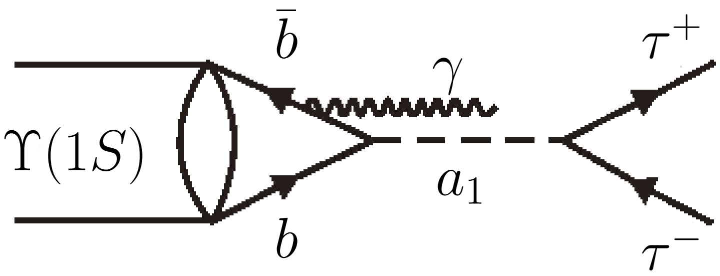
beyond this no straightforward limits, e.g.

- $h \rightarrow \tilde{\chi}_1 \tilde{\chi}_0 \rightarrow (\tilde{\chi}_0 f \bar{f}) \tilde{\chi}_0$ $\quad m_h > 90 - 100$ GeV

  typically a single $f\bar{f}$ does not dominate, the decay through off-shell sleptons ...

...

Light CP-odd Higgs at B factories



The best mode:

$$\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$$

with

$$\sigma_{eff} = 179\,pb.$$

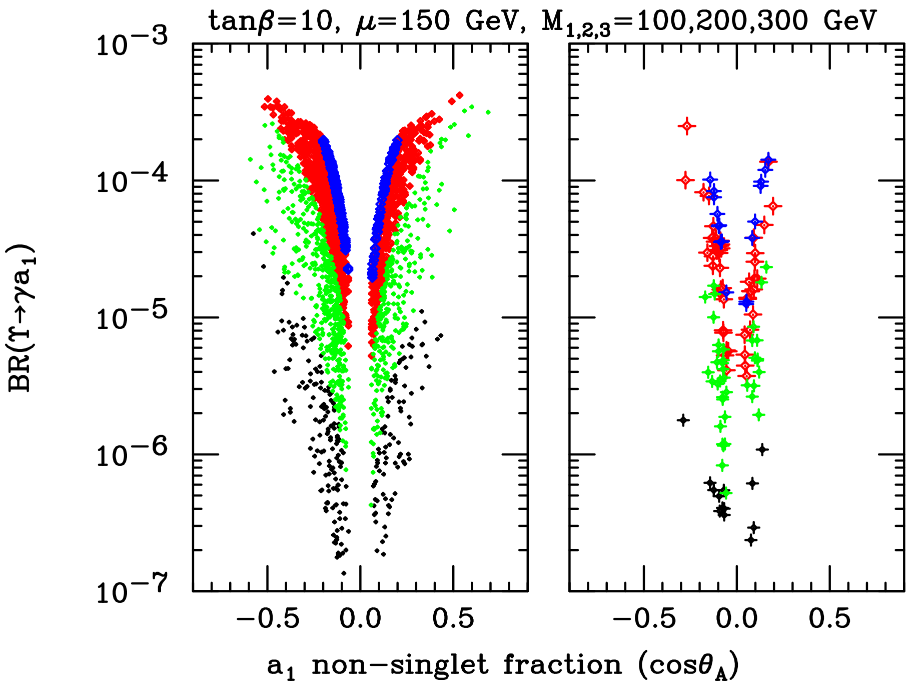
To limit

$$Br(\Upsilon(1S) \to \gamma a_1) \lesssim 10^{-6}$$

we need

$5.6 fb^{-1}/\epsilon$ collected on $\Upsilon(3S)$.

Within reach at existing facilities!



A_κ, A_λ, κ, λ scan $\quad$ $F < 15$ scan

$m_{a_1} < 2m_\tau$

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

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

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

Search at CLEO

CLEO, D. Kreinick, arXiv:0710.5929 [hep-ex]

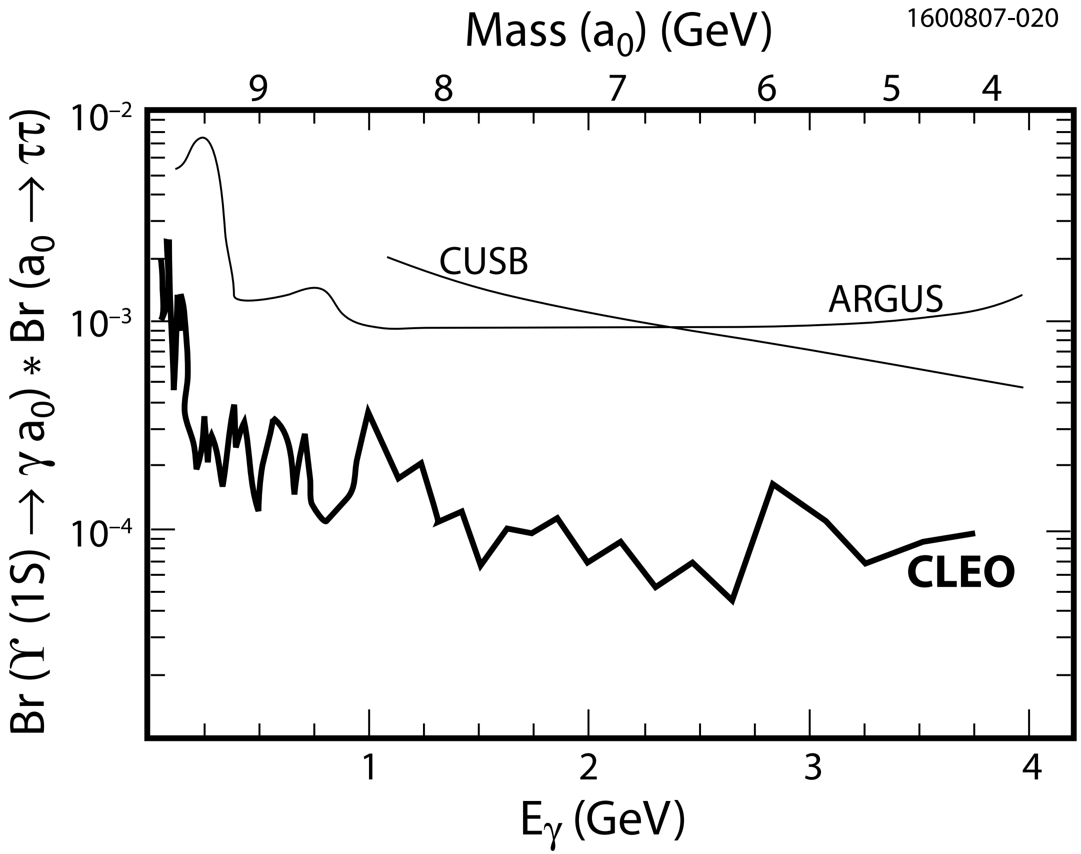


Figure: Upper limits on the branching fraction of $\Upsilon(1S) \to \gamma a_0$ vs. photon energy (bottom scale) and a_0 mass (top scale).

Conclusions

Non-standard Higgs decays

- arise in many models BSM
- allow the Higgs significantly below LEP SM-limit
  - wanted by generic SUSY/natural EWSB
  - preferred by precision EW data
  - “indicated” by LEP data
- modified strategies for Higgs discovery at LEP, Tevatron and LHC

$$h \to 4f,\ 6f,\ \ldots (+MET)$$

- opportunity for B-factories (quarkonium factories)

$$\Upsilon(1S) \to \gamma a_1$$