SUSY AND THE IDEAL HIGGS BOSON

Is it the “God” particle or the “goddamned”* particle?

BSM-LHC, JUNE 4, 2009

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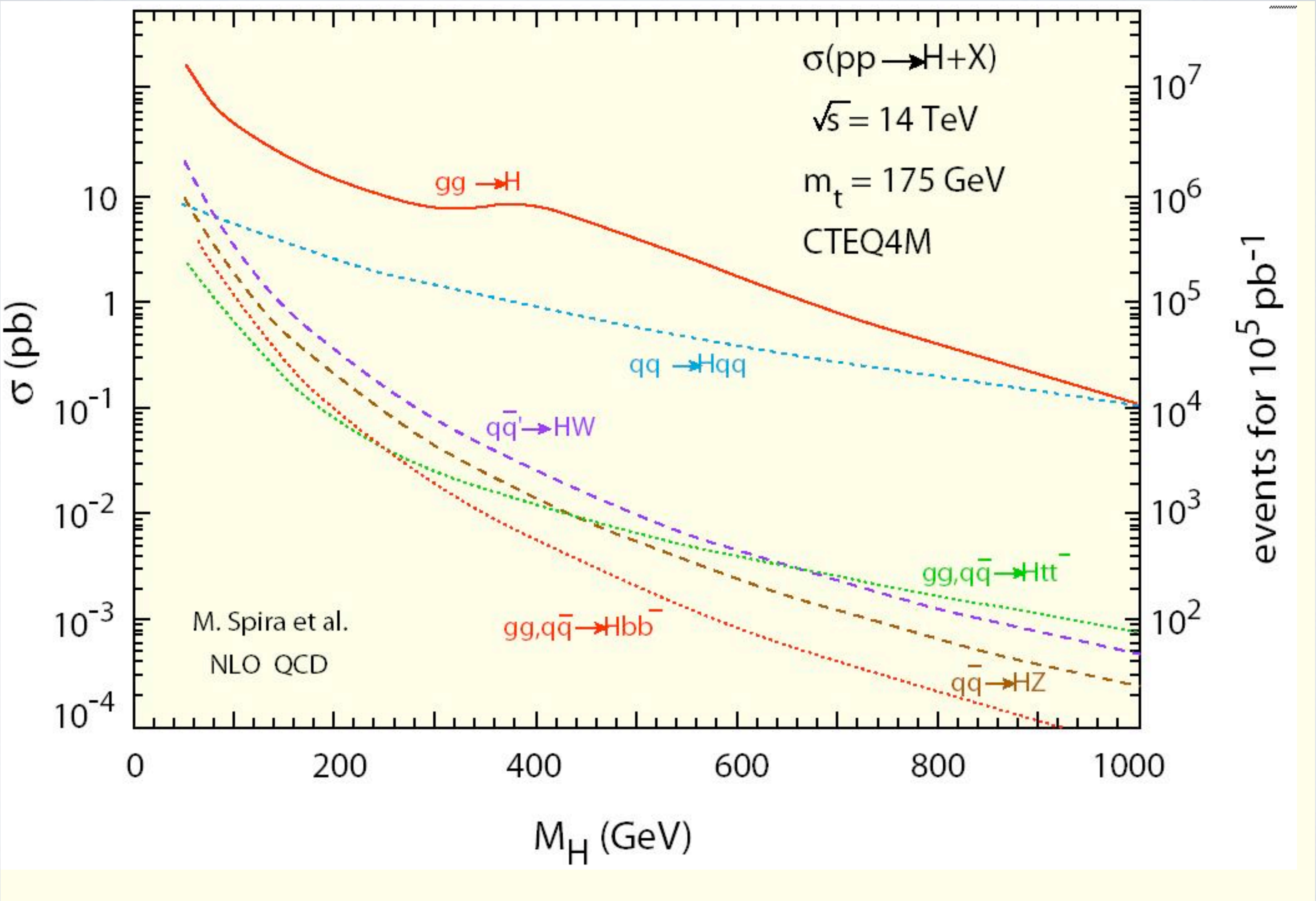
*Attributed to Leon Lederman.

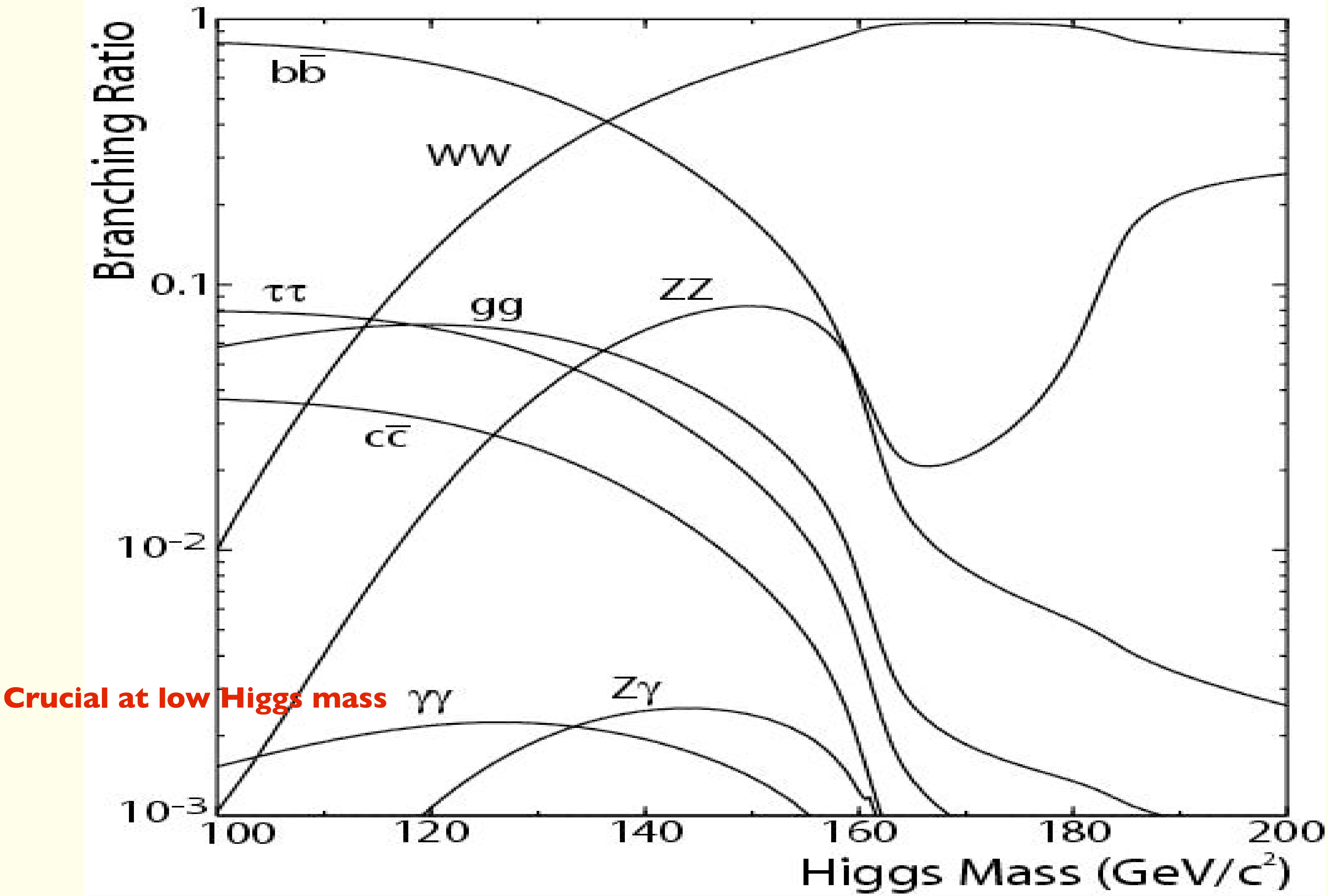
Synopsis/Outline

- Precision Electroweak (PEW) data prefer a light Higgs boson.
- Hierarchy prefers a SUSY solution.
- Gauge coupling unification prefers something close to the MSSM.
- Absence of EWSB fine-tuning requires a light SUSY spectrum (in particular, a light $\widetilde{t}$) and a light $\widetilde{t}$ implies that the SM-like Higgs of SUSY is light.
- Standard MSSM scenarios having a light Higgs with SM-like properties (for PEW perfection) are excluded by LEP.
- Some alternative SUSY models, including the NMSSM (which preserves all good MSSM features and solves the μ problem) give decay scenarios not ruled out by LEP for lighter Higgs mass.
- LHC strategies for finding the Higgs will need to change.

For a Higgs with SM couplings, cross sections are known.
For this talk, I assume only one Higgs carries all ZZ,WW coupling.

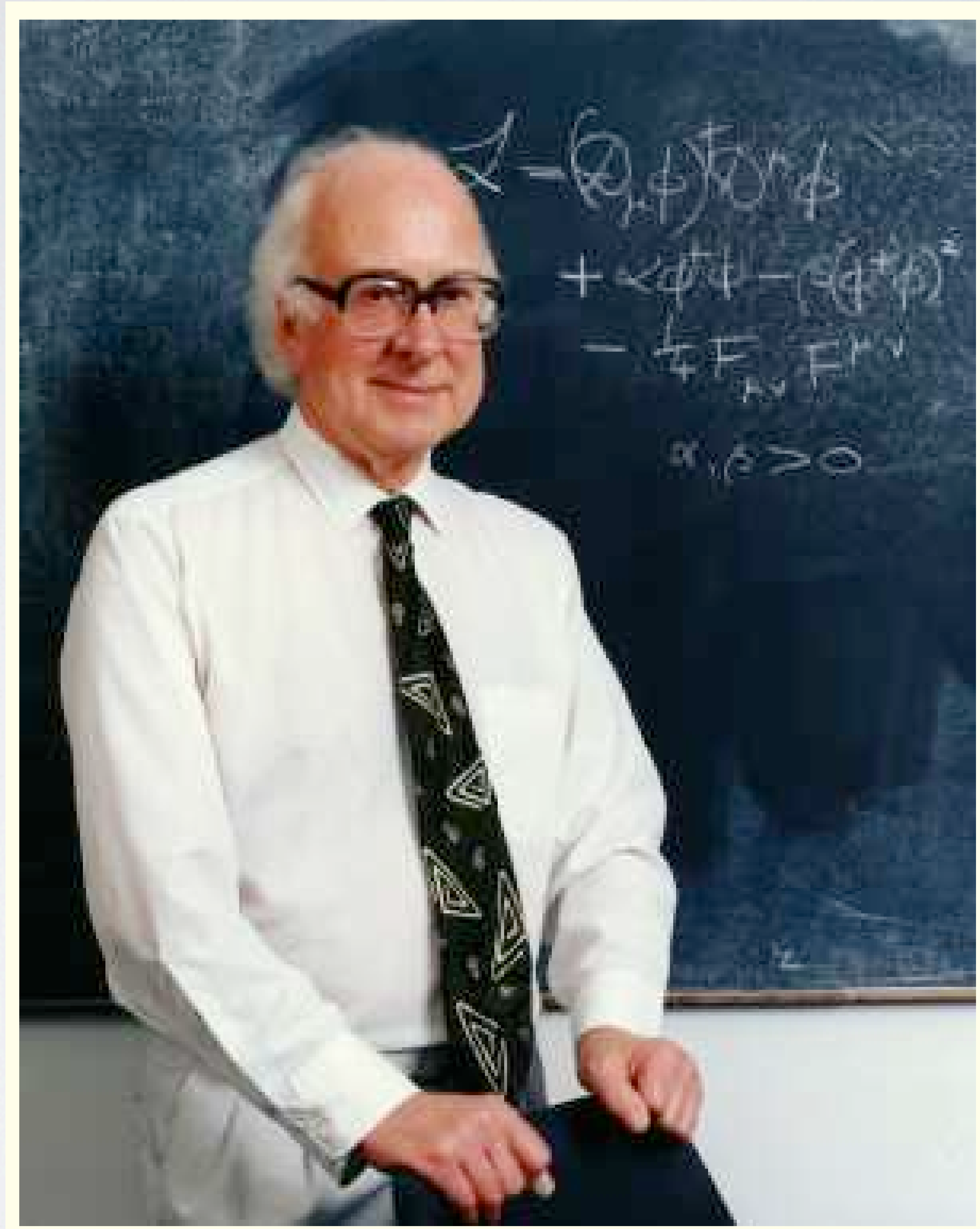


- In the absence of new physics, Higgs decays are also determined by these same couplings.



- However, Beyond the SM physics could completely alter the Higgs decay patterns.

So, what will the Higgs(es) look like?



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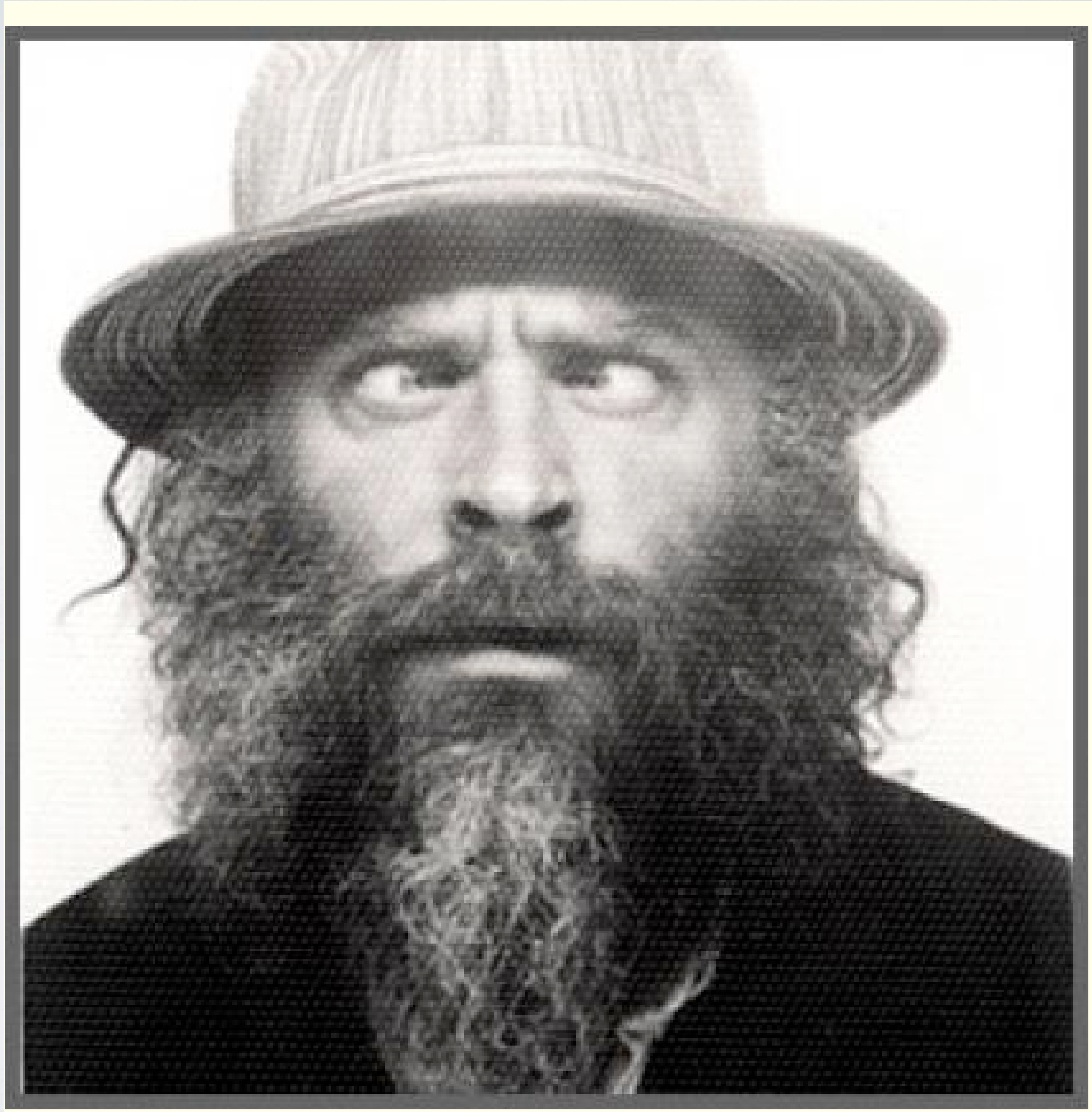
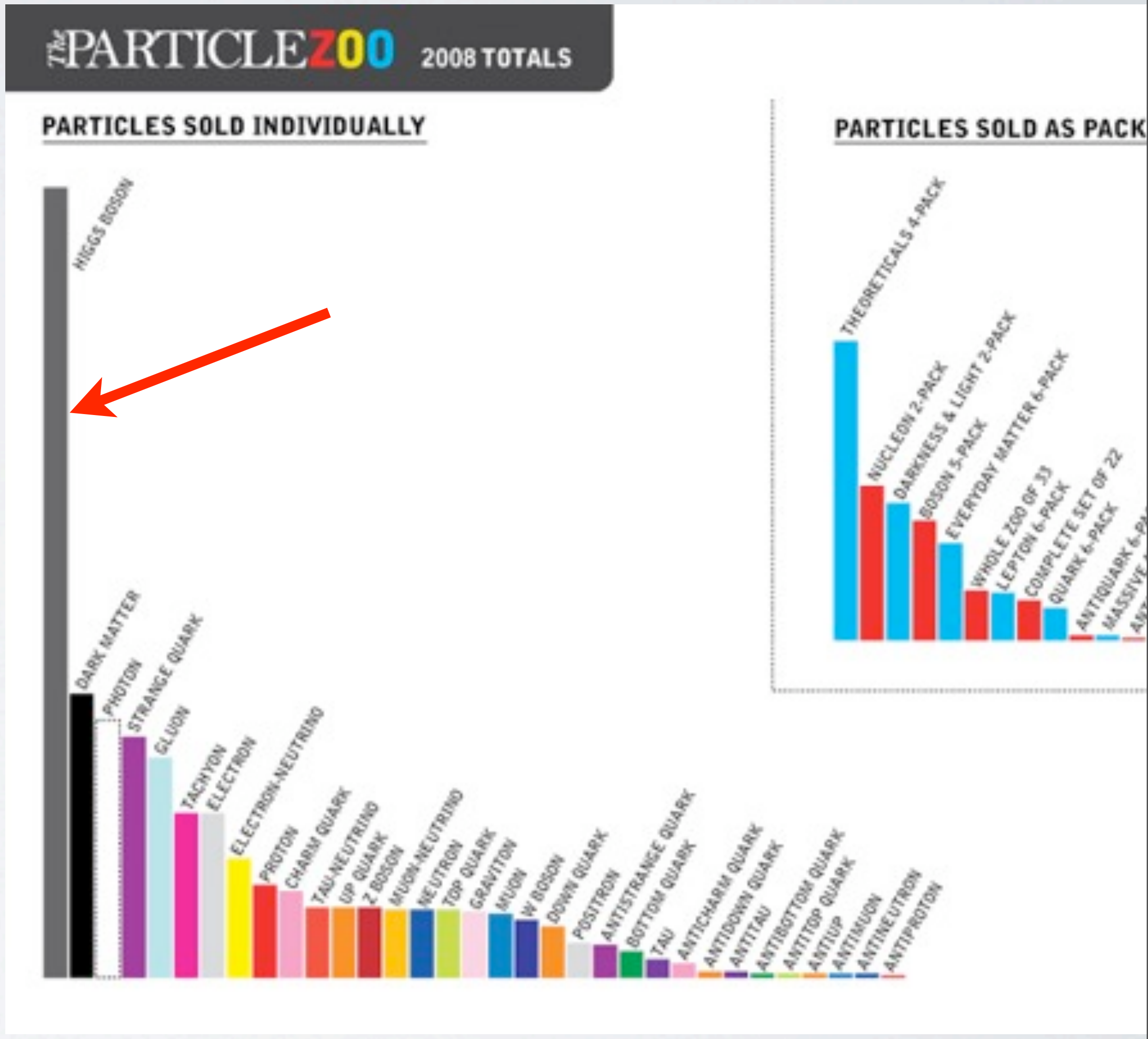


So, what will the Higgs(es) look like?

So, what will the Higgs(es) look like?

If you are too impatient to wait to find a Higgs at the LHC, then you can buy one online.

Attraction of the unknown + familiarity breeds contempt = Higgs by far, the most popular particle.



Or, perhaps you should write a letter to the Higgs.

Dear Higgs Boson,

We know you're out there. We can feel you now. We know that you're afraid. You're afraid of us; you're afraid of change. We don't know the future. We didn't write this to tell you how this is going to end. We wrote this to tell you how it's going to begin.

As you know, our Large Hadron Collider has had some setbacks due to a.... uh... "transformer malfunction" but we know it was you. You sabotaged our machine. We hope you've been enjoying your vacation because we're scheduled to restart in September 2009 and we're pissed.

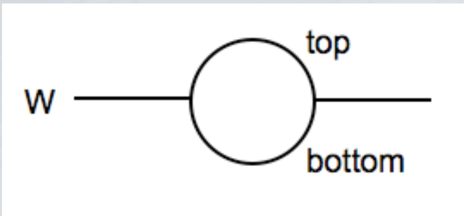
....so run and hide, asshole. Run and hide. If you should get careless and allow yourself to get detected by the Tevatron, we are going to be supremely disappointed; because we want to find you first, and when we do, rest assured we are not going to publish right away. We're going to teach you some manners first.

Love,

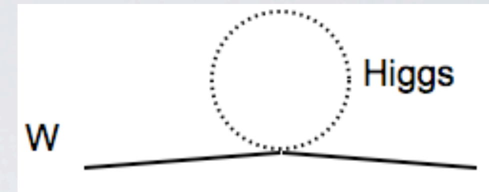
CERN

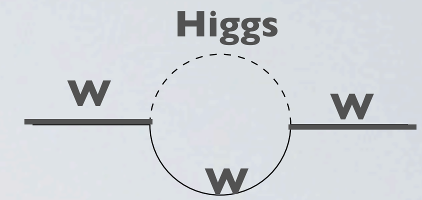
CERN may come to regret this hope.

Precision Electroweak data from LEP and the Tevatron creates large tension within the SM.



$$m_W = m_W^0 + c_1 m_t^2 + c_2 \log m_H^2$$



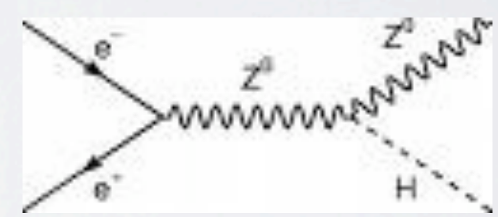


✻ LEP PEW overall fit prefers Higgs mass near 80 GeV w. 95% upper bound of about 160 GeV.

✻ LEP PEW data without hadronic asymmetries prefers Higgs mass of about 50 GeV and below 105 GeV at 95% CL.

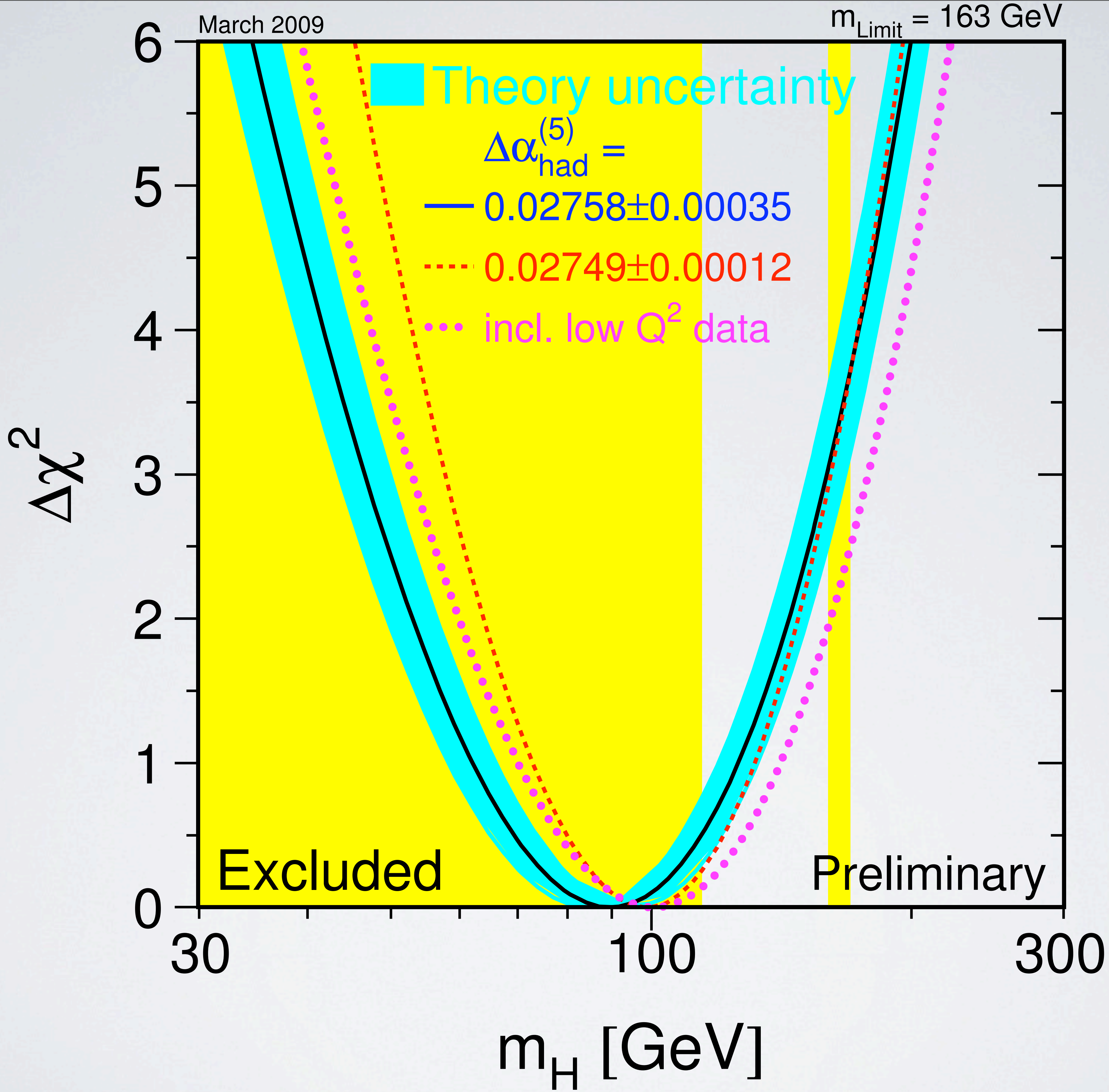
✻ Tevatron W mass + top mass prefers quite light SM Higgs.

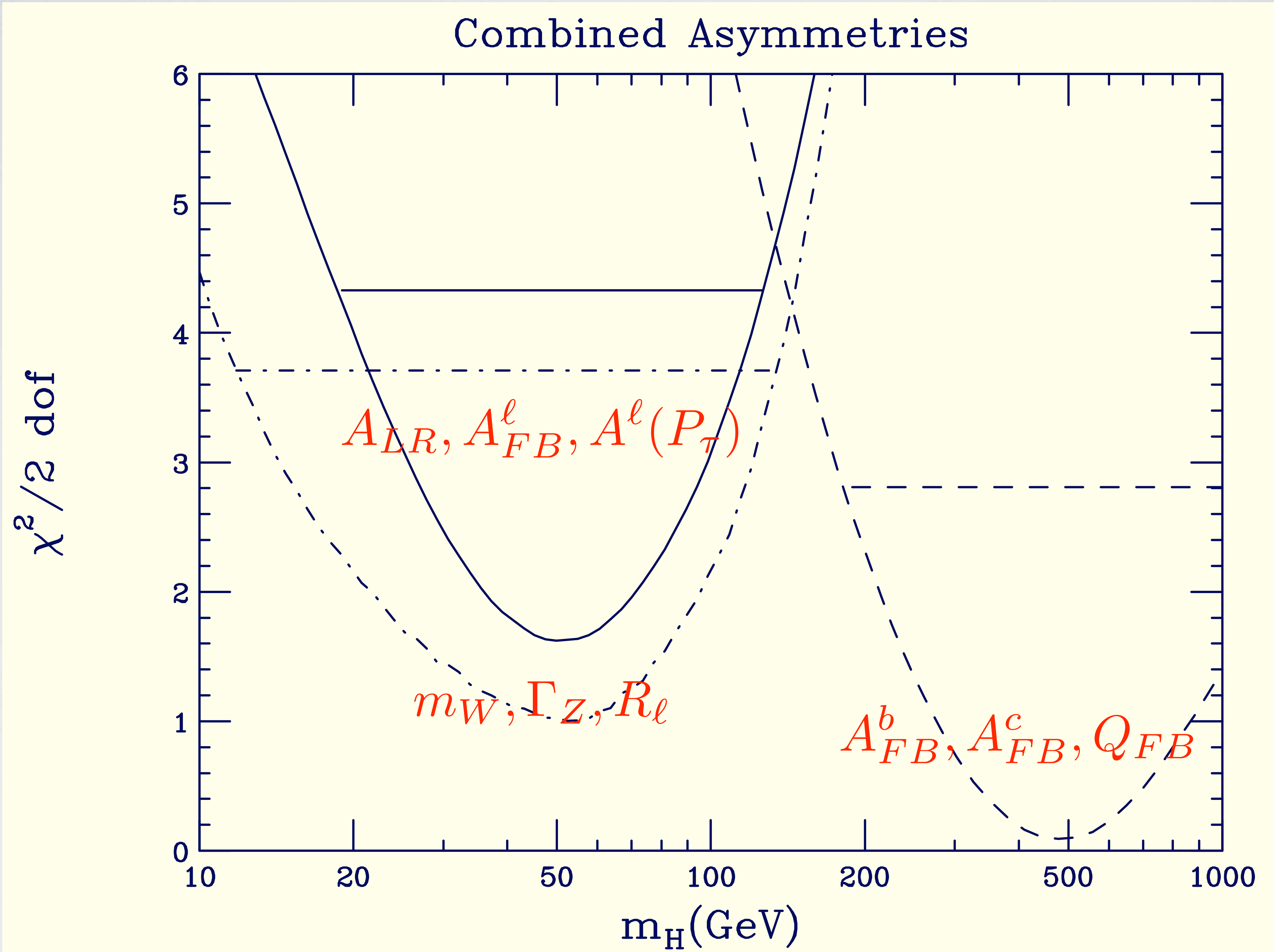
✻ **BUT!** LEP requires SM Higgs heavier than 114 GeV.



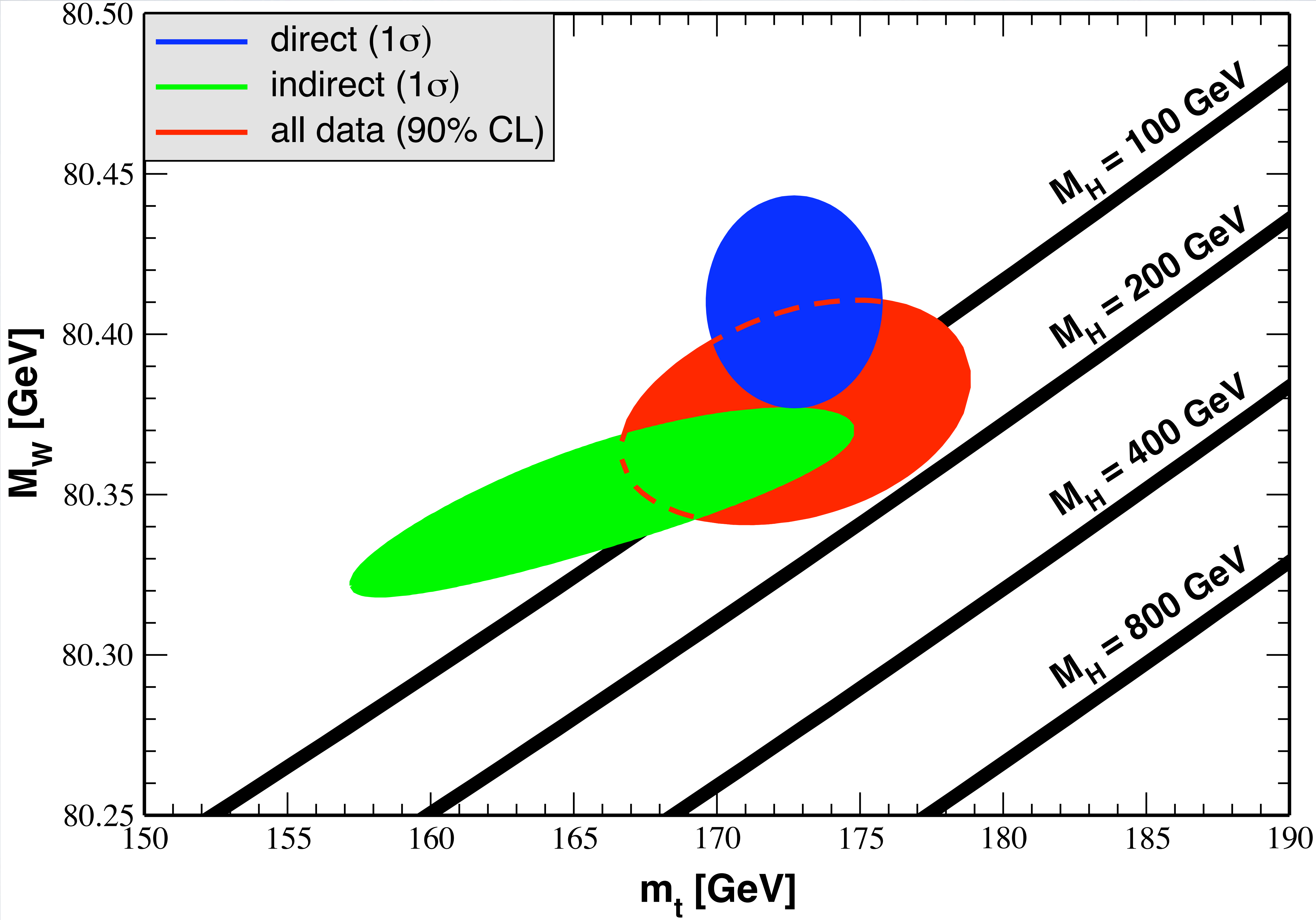
And, the Tevatron has excluded a range near $2m_W$.

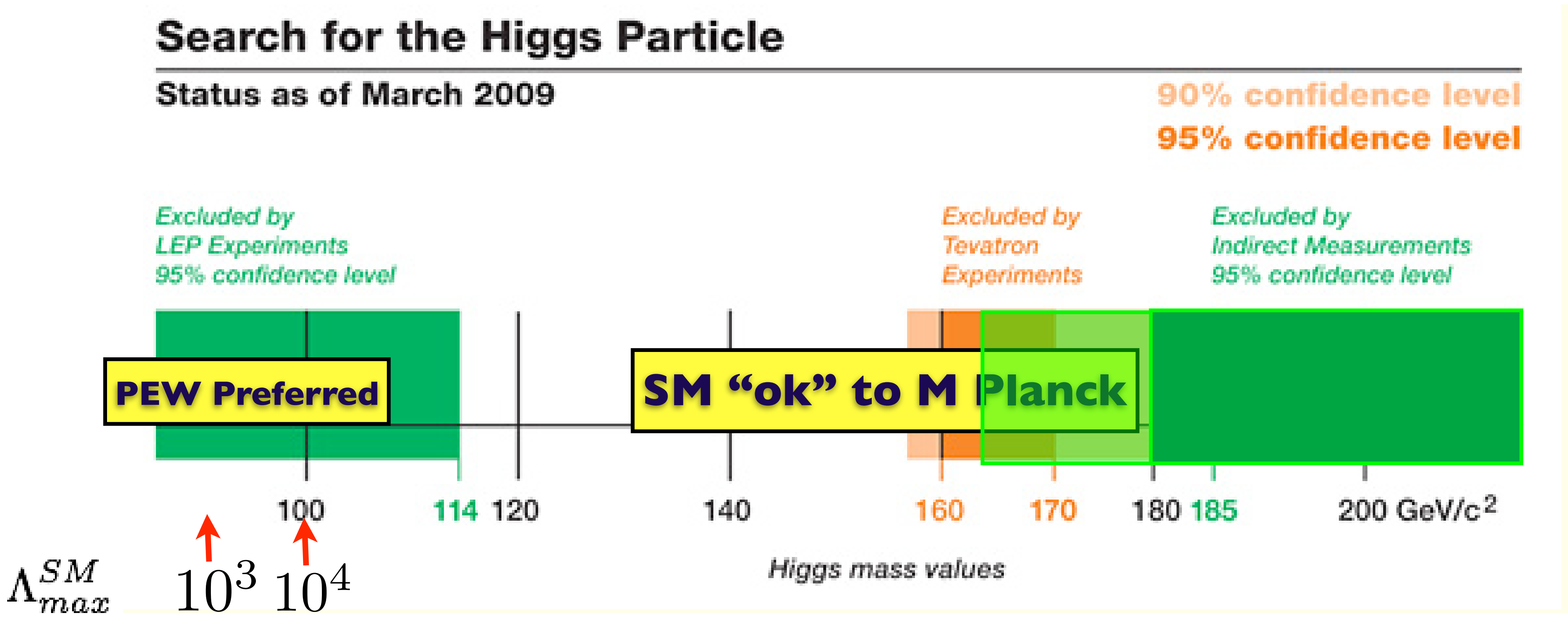
Don't forget: low Higgs mass is also good for electroweak baryogenesis.


March 2009
m_{Limit} = 163 GeV
Theory uncertainty
$\Delta\alpha_{had}^{(5)}$ =
0.02758±0.00035
0.02749±0.00012
incl. low Q^2 data
$\Delta\chi^2$
Excluded
Preliminary
m_H [GeV]
0
1
2
3
4
5
6
30
100
300



From Chanowitz.


direct (1σ)
indirect (1σ)
all data (90% CL)
M_H = 100 GeV
M_H = 200 GeV
M_H = 400 GeV
M_H = 800 GeV
80.50
80.45
80.40
80.35
80.30
80.25
150
155
160
165
170
175
180
185
190
M_W [GeV]
m_t [GeV]



✻ ESCAPE = BSM decays

Table 1: LEP m_H Limits for a H with SM-like ZZ coupling, but varying decays. See (S. Chang, R. Dermisek, J. F. Gunion and N. Weiner, Ann. Rev. Nucl. Part. Sci. 58, 75 (2008) [arXiv:0801.4554 [hep-ph]]).

Invisible decays don't "help"

Mode	SM modes	2τ or $2b$ *only*	$2j$	$WW^* + ZZ^*$	$\gamma\gamma$	$\not{E}$	$4e, 4\mu, 4\gamma$
Limit (GeV)	114.4	115	113	100.7	117	114	114?
Mode	$4b$	4τ	any (e.g. $4j$)	$2f + \not{E}$			
Limit (GeV)	110	86	82	90?			

When must new physics appear if the SM is treated as an effective theory?

- the Higgs self coupling should not blow up below scale Λ; $\Rightarrow$ upper bound on $m_{h_{\rm SM}}$ as function of Λ.

- the Higgs potential should not develop a new minimum at large values of the scalar field of order Λ; $\Rightarrow$ lower bound on $m_{h_{\rm SM}}$ as function of Λ.

These two constraints imply that the SM can be valid all the way up to $M_{\rm P}$ if $130 \lesssim m_{h_{\rm SM}} \lesssim 180~{\rm GeV}$.

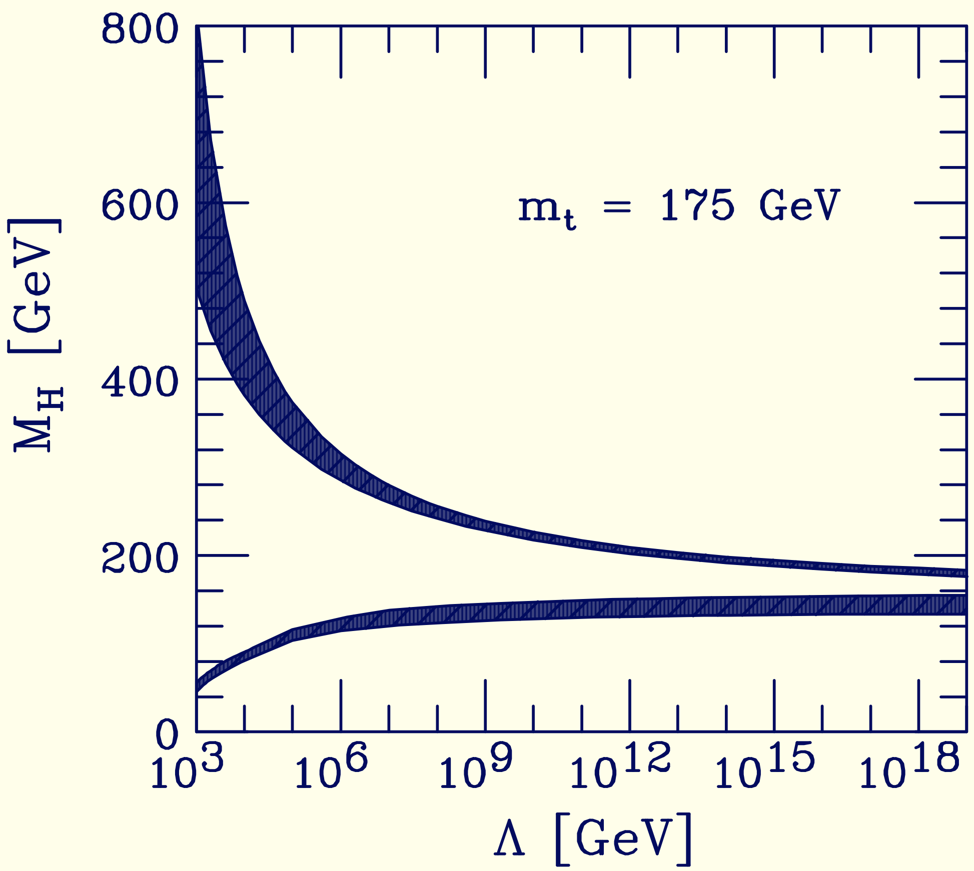


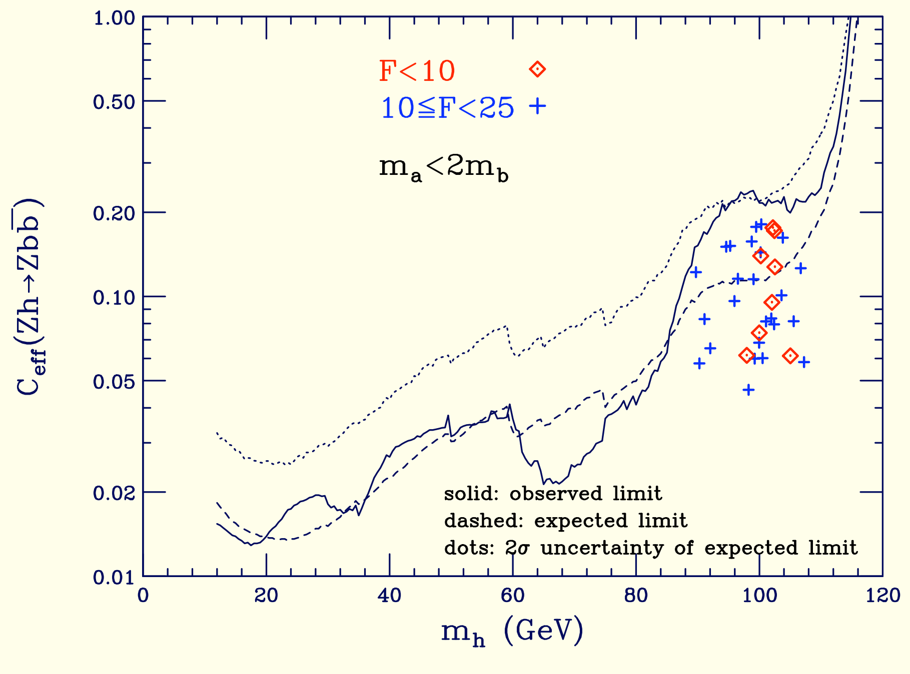
Figure 1: Triviality and global minimum constraints on $m_{h_{\rm SM}}$ vs. Λ.

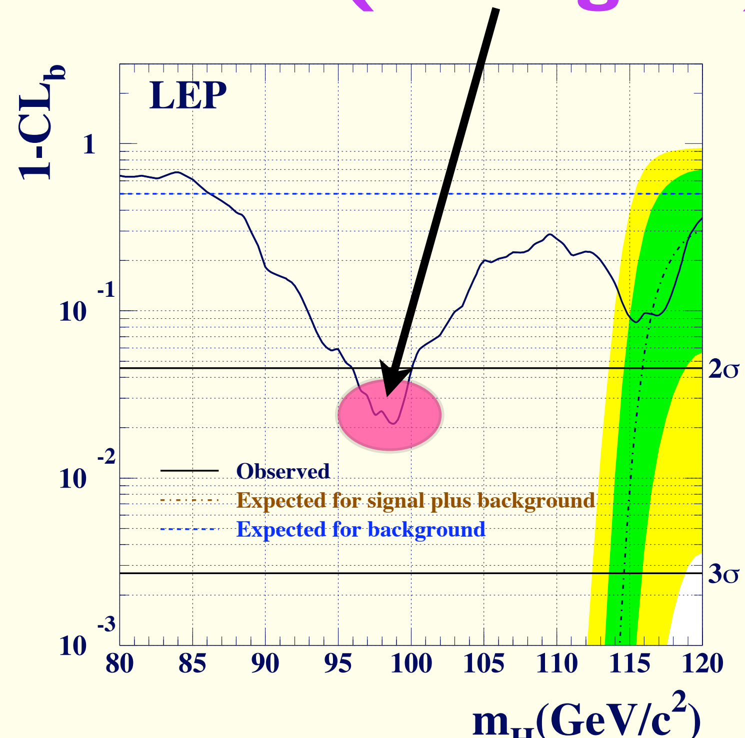
One generic way of having a low LEP limit on m_H is to suppress the $H \to b\bar{b}$ branching ratio by having a light a (or h)with $B(H \to aa) > 0.7$ and $m_a < 2m_b$ (to avoid LEP $Z + 4b$ limit at $110~\mathrm{GeV}$, i.e. above ideal). For $2m_\tau < m_a < 2m_b$, $a \to \tau^+\tau^-$. For $m_a < 2m_\tau$, $a \to jj$.
See: (R. Dermisek and J. F. Gunion, Phys. Rev. Lett. 95, 041801 (2005) [arXiv:hep-ph/0502105]; R. Dermisek and J. F. Gunion, Phys. Rev. D 73, 111701 (2006) [arXiv:hep-ph/0510322])

Since the $Hb\bar{b}$ coupling is so small, very modest Haa coupling suffices.

An attractive possibility: $m_H \sim 100~\mathrm{GeV}$ and $BR(H \to b\bar{b}) \sim 0.1$

Explains largest LEP excess (2.3 sigma).

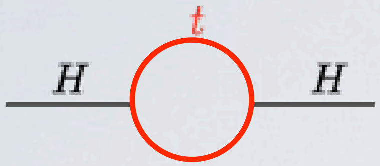




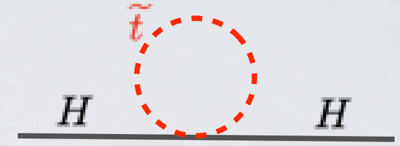
Extra Higgs (complex) singlets are abundant in most string vacua, but especially well-motivated in SUSY.

Why SUSY?

Solves hierarchy problem if at a TeV and PEW needs new physics there anyway.



$m_H^2 = (m_H^0)^2 - c\Lambda^2$



$\delta m_H^2 \sim c(\Lambda^2 + m_{\tilde{t}}^2)$

- **The MSSM comes close to being very nice.**

If we assume that all sparticles reside at the $\mathcal{O}(1\ \mathrm{TeV})$ scale and that μ is also $\mathcal{O}(1\ \mathrm{TeV})$, then, the MSSM has two particularly wonderful properties.

1. $\boxed{\textbf{Gauge Coupling Unification}}$

Standard Model **MSSM**

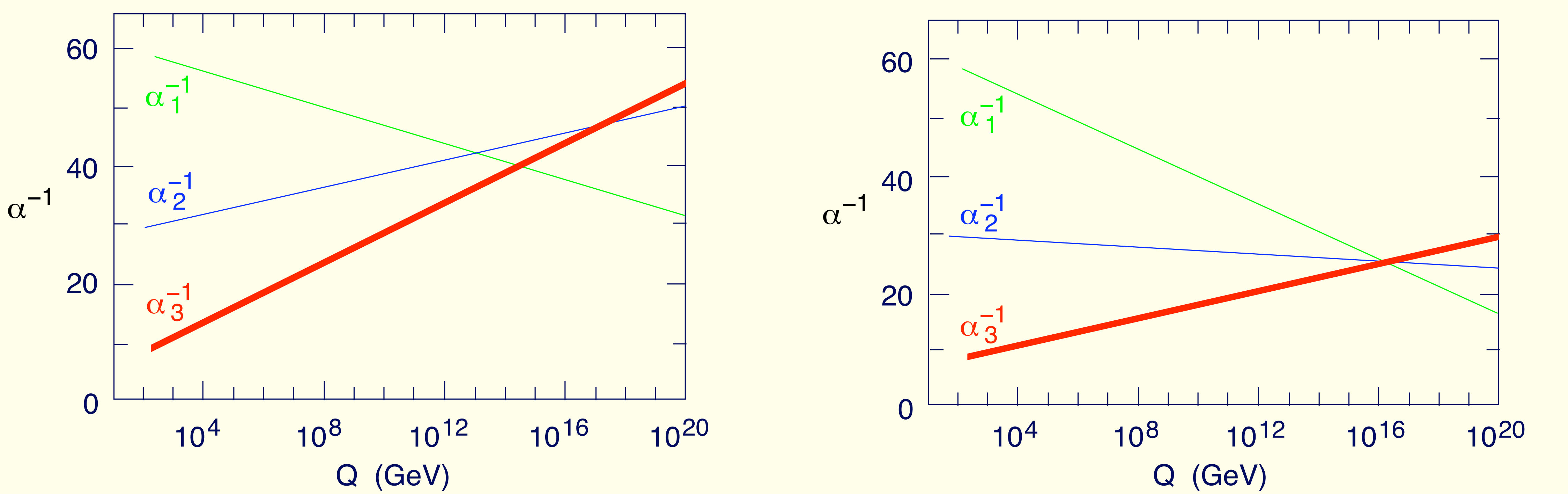


Figure 4: Unification of couplings constants ($\alpha_i = g_i^2/(4\pi)$) in the minimal supersymmetric model (MSSM) as compared to failure without supersymmetry.

2. RGE EWSB

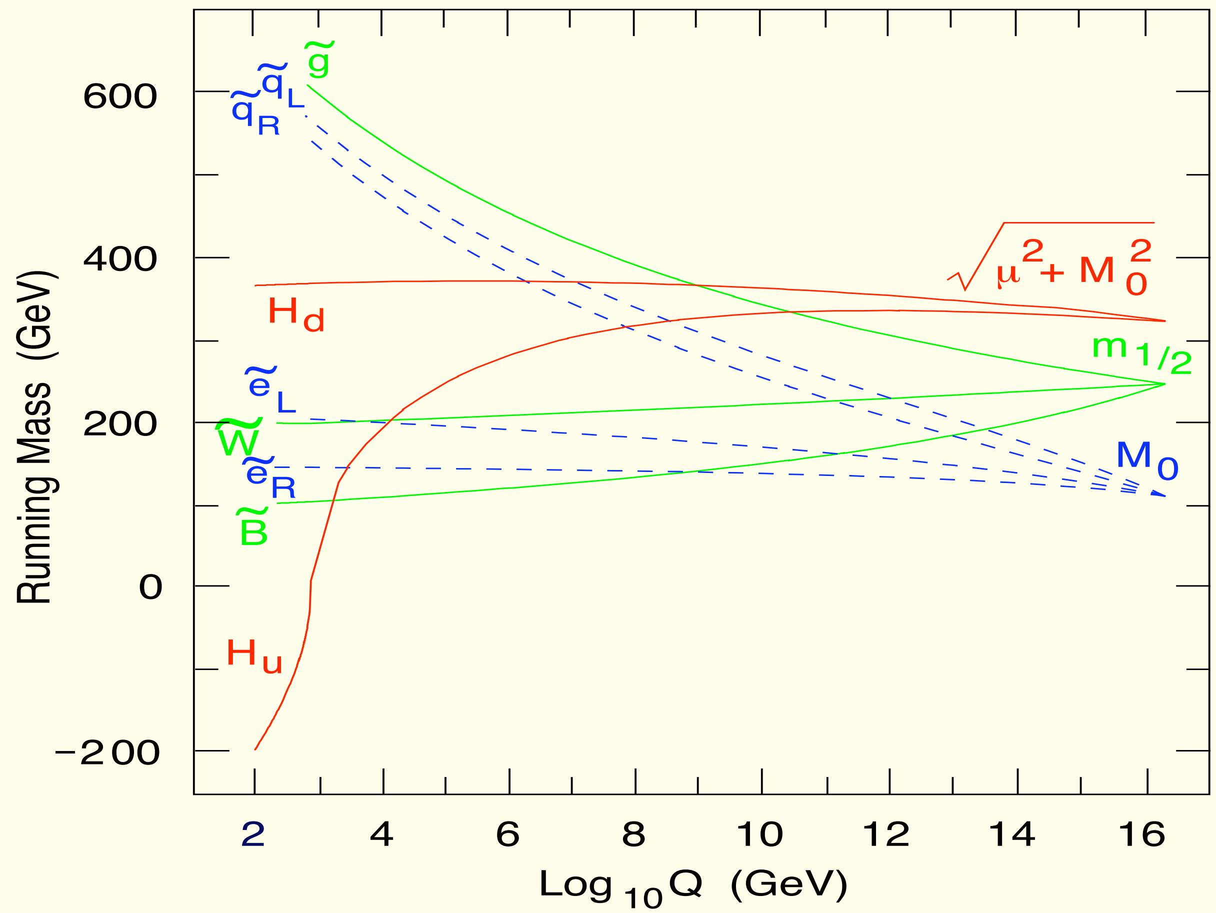


Figure 5: **Evolution of the (soft) SUSY-breaking masses or masses-squared, showing how $m^2_{H_u}$ is driven < 0 at low $Q \sim \mathcal{O}(m_Z)$.**

But, must one fine-tune the GUT scale parameters to get correct Z mass?

F **measures the degree to which GUT parameters must be tuned.**

Want $F < 10$ **. This requires** $m_{\tilde{t}} < 400~\mathrm{GeV}$ **and a light gluino.**

For such a stop mass the MSSM and other SUSY models *predict* that $m_h < 110~\mathrm{GeV}$ **.**

MSSM Higgs sector: h, H, A **with** h **typically SM-like unless it is very light and** H **is SM-like.**

The problem: the light Higgs of the MSSM decays like the SM Higgs and is basically excluded for $m_h < 114~\mathrm{GeV}$. This implies that $m_{\tilde{t}} > 800~\mathrm{GeV}$ which in turn implies $F > 50$ = very bad!

What is needed is a SUSY model for which the stop mass can be low but for which the resulting light <100 GeV Higgs is not excluded by LEP.

LEP exclusion can be avoided by having unusual decays as seen earlier.

My favorite SUSY model is the Next to Minimal Supersymmetric Model (NMSSM). It has an a *of the type needed* and retains the supersymmetric solution to the hierarchy problem.

The a comes mainly from the singlet, S , field that solves the famous mu-problem of the MSSM and was the initial motivation for the NMSSM.

$$W \ni \mu \widehat{H}_u \widehat{H}_d \quad \text{MSSM} \quad vs. \quad W \ni \lambda \widehat{S} \widehat{H}_u \widehat{H}_d \to \lambda \langle S \rangle \widehat{H}_u \widehat{H}_d \quad \text{NMSSM}$$

A_λ, A_κ are the new soft-SUSY-breaking parameters.

The required properties of the a are natural in the NMSSM. In particular, there is a $U(1)_R$ symmetry in the limit of $A_\lambda, A_\kappa \to 0$ that, if exact, predicts that the a would be massless. This symmetry, if exact at the GUT scale, is weakly broken in evolving down from the GUT scale. Getting correct $H \to aa$ branching ratio need not be fine-tuned. More later.

And, very importantly, the NMSSM yields (like the MSSM) gauge coupling unification and "radiative" electroweak symmetry breaking.

Other SUSY decays that would escape strongest LEP limits:

$$h \to \widetilde{\chi}_1^0 + \widetilde{\chi}_2^0 \to \widetilde{\chi}_1^0 + \widetilde{\chi}_1^0 + f\overline{f} \to E_{miss} + f\overline{f}$$

$$h \to \widetilde{\chi}_1^0 + \widetilde{\chi}_1^0 \to \widetilde{G} + \widetilde{G} + \gamma + \gamma \to E_{miss} + \gamma + \gamma$$

LEP limits for the latter are not known, but maybe they would have noticed this decay if the Higgs were below 114 GeV?

Note: the above are some natural cases assuming R-parity conserving SUSY so that there will be a dark matter candidate. There are many more SUSY models with unusual Higgs decays related to R-parity violation and similar that would, however, not allow for a dark matter particle.

There are also many BSM approaches in which the electroweak Higgs (i.e. the one with ZZ coupling) decays invisibly.

As noted earlier, LEP constrains an invisibly decaying Higgs as strongly as if it decayed a la SM. From the PEW perspective this is not desirable.

Detecting the light h of the NMSSM

LHC

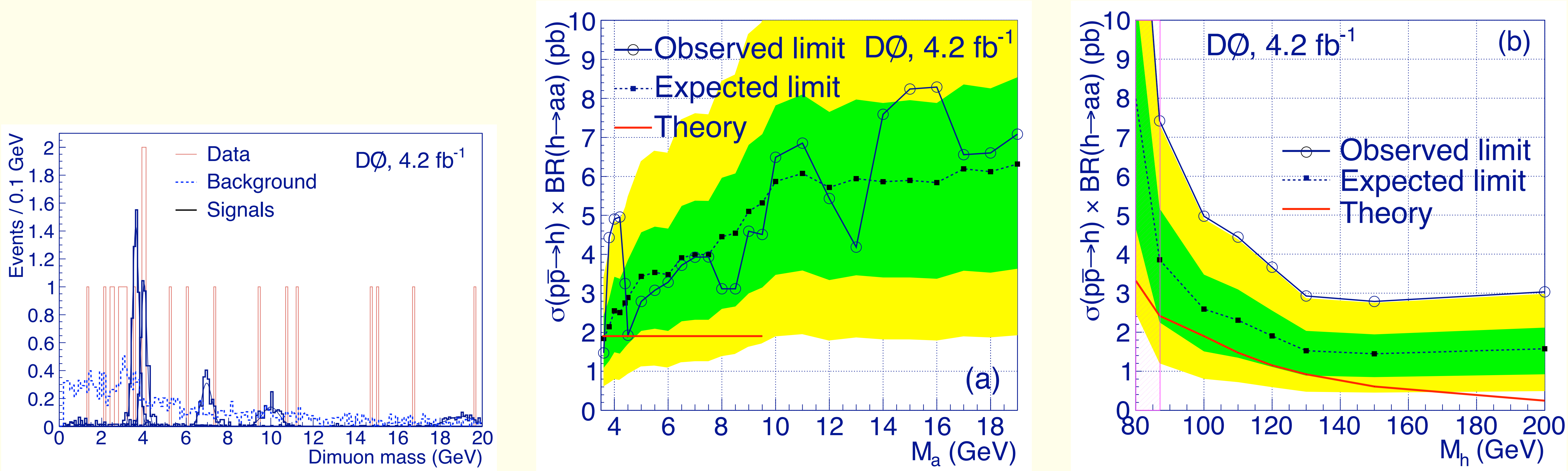
All standard LHC channels fail: $e.g.$ $B(h \to \gamma\gamma)$ is much too small because of large $B(h \to aa)$.

The possible new LHC channels include:

1. $gg \to h \to aa \to 4\tau$ and $2\tau + \mu^+\mu^-$

   Always use μ tag for accepted events. $2\tau + 2\mu$ is main signal source after cuts.

   There is an actual D0 analysis (A. Haas et. al.) of this mode using about $L \sim 4~\mathrm{fb}^{-1}$ of data. There are even small $\sim 1\sigma$ excesses for $m_a \sim 4$ and $10 - 11~\mathrm{GeV}$ consistent with predicted signal. About $L \sim 40~\mathrm{fb}^{-1}$ would be needed for a 3σ signal.



From arXiv:0905.3381.

At the LHC? Studied by Wacker et al.

- $\sigma(gg \to h) \sim 50 \text{ pb}$ for $m_h \sim 100 \text{ GeV}$.
- $B(h \to aa) \sim 0.8 - 0.9$.
- $B(a \to \mu^+\mu^-) \sim 0.0035 - 0.004$ and $B(a \to \tau^+\tau^-) \sim 0.95 - 0.98$
- Useful branching ratio product is $2 \times B(a \to \mu^+\mu^-) B(a \to \tau^+\tau^-) \sim .0075$.
- Cut efficiencies $\epsilon \sim 0.018$.

- **Net useful cross section:**

$$\sigma(gg \to h)B(h \to aa)[2B(a \to \mu^+\mu^-)B(a \to \tau^+\tau^-)]\epsilon \sim 4 - 7 \text{ fb}. \tag{25}$$

Backgrounds are small so perhaps 10 events in a single $\mu^+\mu^-$ bin would be convincing $\Rightarrow$ need about $L = 2 \text{ fb}^{-1}$.

Note: If $m_a < 2m_\tau$, then $B(a \to \mu^+\mu^-) > 0.06$ and

$$\sigma(gg \to h)B(h \to aa)[B(a \to \mu^+\mu^-]^2\epsilon > (153 \text{ fb}) \times \epsilon. \tag{26}$$

If $\epsilon > 0.02$ (seems likely) then $\Rightarrow \sigma_{eff} > 3$ fb. This should be really background free and would close the $m_a < 2m_\tau$ "window of worry".

2. $WW \to h \to aa \to \tau^+\tau^- + \tau^+\tau^-$.

Key will be to tag relevant events using spectator quarks and require very little activity in the central region by keeping only events with 4 or 6 tracks.

Looks moderately promising but far from definitive results at this time (see, A. Belyaev *et al.*, arXiv:0805.3505 [hep-ph] and our work, JFG+Tait+Z. Han, below). More shortly.

3. $t\bar{t}h \rightarrow t\bar{t}aa \rightarrow t\bar{t} + \tau^+\tau^- + \tau^+\tau^-$.

No study yet. Would isolated tracks/leptons from τ's make this easier than $t\bar{t}h \rightarrow t\bar{t}b\bar{b}$?

4. $W, Z + h \rightarrow W, Z + aa \rightarrow W, Z + \tau^+\tau^- + \tau^+\tau^-$.

Leptons from W, Z and isolated tracks/leptons from τ's would provide a clean signal. No study yet.

5. $\widetilde{\chi}_2^0 \rightarrow h\widetilde{\chi}_1^0$ with $h \rightarrow aa \rightarrow 4\tau$.

(Recall that the $\widetilde{\chi}_2^0 \rightarrow h\widetilde{\chi}_1^0$ channel provides a signal in the MSSM when $h \rightarrow b\bar{b}$ decays are dominant.)

6. Last, but definitely not least: diffractive production $pp \rightarrow pph \rightarrow ppX$.

The mass M_X can be reconstructed with roughly a $1 - 2~\mathrm{GeV}$ resolution, potentially revealing a Higgs peak, independent of the decay of the Higgs.

The event is quiet so that the tracks from the τ's appear in a relatively clean environment, allowing track counting and associated cuts.

Signal significances from JFG, Forshaw, Pilkington, Hodgkinson, Papaefstathiou: arXiv:0712.3510 are plotted in Fig. 6 for a variety of luminosity and triggering assumptions.

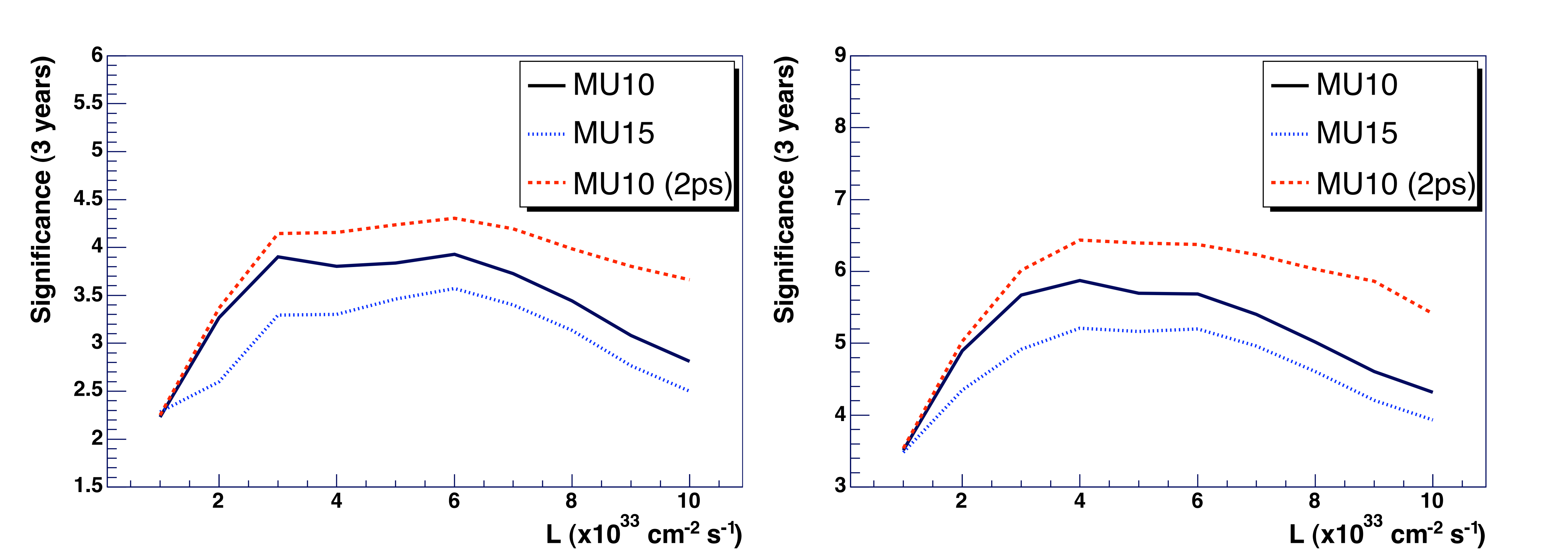


Figure 6: (a) The significance for three years of data acquisition at each luminosity. (b) Same as (a) but with twice the data. Different lines represent different μ trigger thresholds and different forward detector timing. Some experimentalists say more efficient triggering is possible, doubling the number of events at given luminosity.

CMS folk claim we can increase our rates by about a factor of 2 to 3 using additional triggering techniques.

The Collinearity Trick

- Since $m_a \ll m_h$, the a's in $h \to aa$ are highly boosted.

  $\Rightarrow$ the a decay products will travel along the direction of the source a.

  $\Rightarrow$ $p_a \propto \sum$ visible 4-momentum of the charged tracks in its decay. Labeling the two a's with indices 1 and 2 we have

$$p_i^{vis} = f_i \, p_{a,i} \tag{25}$$

  where $1 - f_i$ is the fraction of the a momentum carried away by neutrals.

- $\boxed{pp \to pph \text{ case}}$

  The accuracy of this has now been tested in the $pp \to pph$ case, and gives an error for m_h of order $5~\mathrm{GeV}$, but this is less accurate than m_h determination from the tagged protons and so is not used.
  However, we are able to make *four* m_a determinations per event.

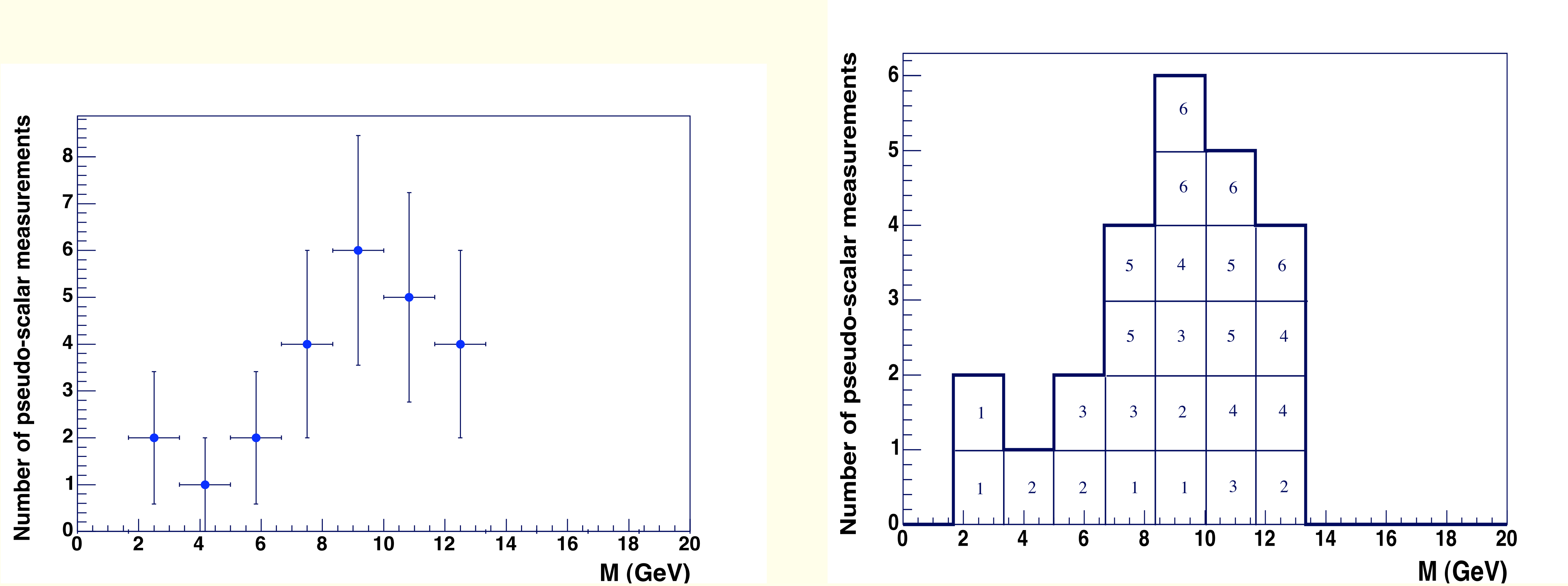


Figure 7: (a) A typical a mass measurement. (b) The same content as (a) but with the breakdown showing the 4 Higgs mass measurements for each of the 6 events, labeled $1-6$ in the histogram.

Figure 7 shows the distribution of masses obtained for $180\ \mathrm{fb}^{-1}$ of data collected at 3×10^{33} cm^{-2}s^{-1}, corresponding to about 6 Higgs events and therefore 24 m_a entries.

By considering many pseudo-data sets, we conclude that a typical experiment would yield $m_a = 9.3 \pm 2.3$ GeV, which is in re-assuringly good agreement with the input value of $9.7\ \mathrm{GeV}$.

- $\boxed{WW \to h}$

For $m_h = 100$ GeV and SM-like WWh coupling, $\sigma(WW \to h) \sim 7$ pb, implying 7×10^5 events before cuts for $L = 100$ fb^{-1}.
In this case, we do not know the longitudinal momentum of the h, but we should have a good measurement of its transverse momentum from the tagging jets and other recoil jets.
This gives two equations in the two unknown $f_{1,2}$ and allows us to solve and construct mass peaks.

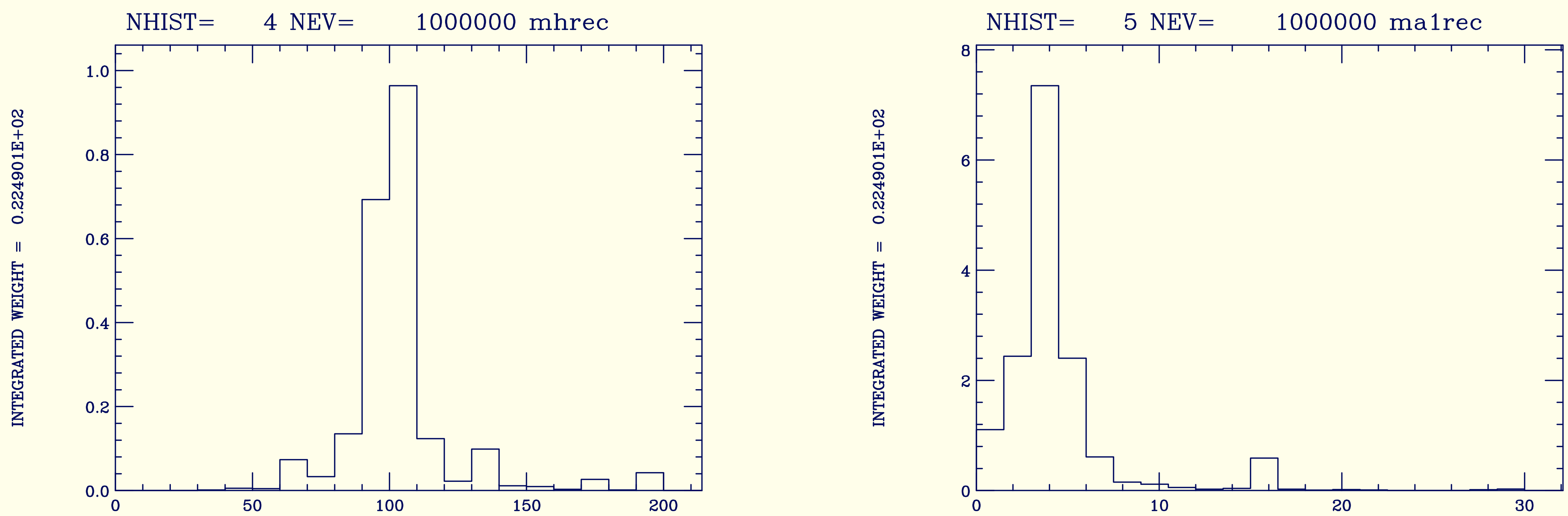


Figure 8: (a) A typical h mass distribution. (b) A typical a mass distribution. No cuts imposed; signal only

Thursday, June 4, 2009

Other related scenarios

- A string of Higgs, as possibly hinted at by the CDF multi-muon events.

  The SM-like Higgs could then decay into a string of Higgs bosons.

  (Ellwanger et al have an NMSSM model that gives CDF multi-muon, but implications for unusual h decays are unclear.)

- Many singlets, as generically possible in string models, could mix with the doublet Higgs and create a series of Higgs eigenstates (with mass weight in the $< 100~\mathrm{GeV}$ region for good PEW).

  It can be arranged that these eigenstates decay in complex ways that would have escaped LEP limits.

  In fact, one can get really low "effective" Higgs mass from PEW point of view while fitting under LEP constraint curve.

  This is the "worst case" scenario envisioned long ago in JFG, Espinosa: hep-ph/9807275.

- **Low $\tan\beta$ NMSSM scenarios in which the first two CP-even Higgs bosons both have mass in the $\lesssim 100~\mathrm{GeV}$ region and decay so as to escape LEP (and Tevatron) limits. See later section.**

- **Drop dark matter requirement: $\Rightarrow$ huge plethora of possibilities in SUSY.**

Includes "hidden valley" decays, R-parity violating decays, ...

ILC

At the ILC, there is no problem since $e^+e^- \to ZX$ will reveal a $M_X \sim m_h \sim 90 - 100~\mathrm{GeV}$ peak no matter how the h decays.

If there are many Higgs, then the excesses in various bins of M_X will be apparent even if there is a broad sort of spectrum and X has a mixture of decays.

But the ILC is decades away.

A few further points regarding a light a

- Define the mass eigenstate: $a = \cos\theta_A a_{MSSM} + \sin\theta_A a_S$.

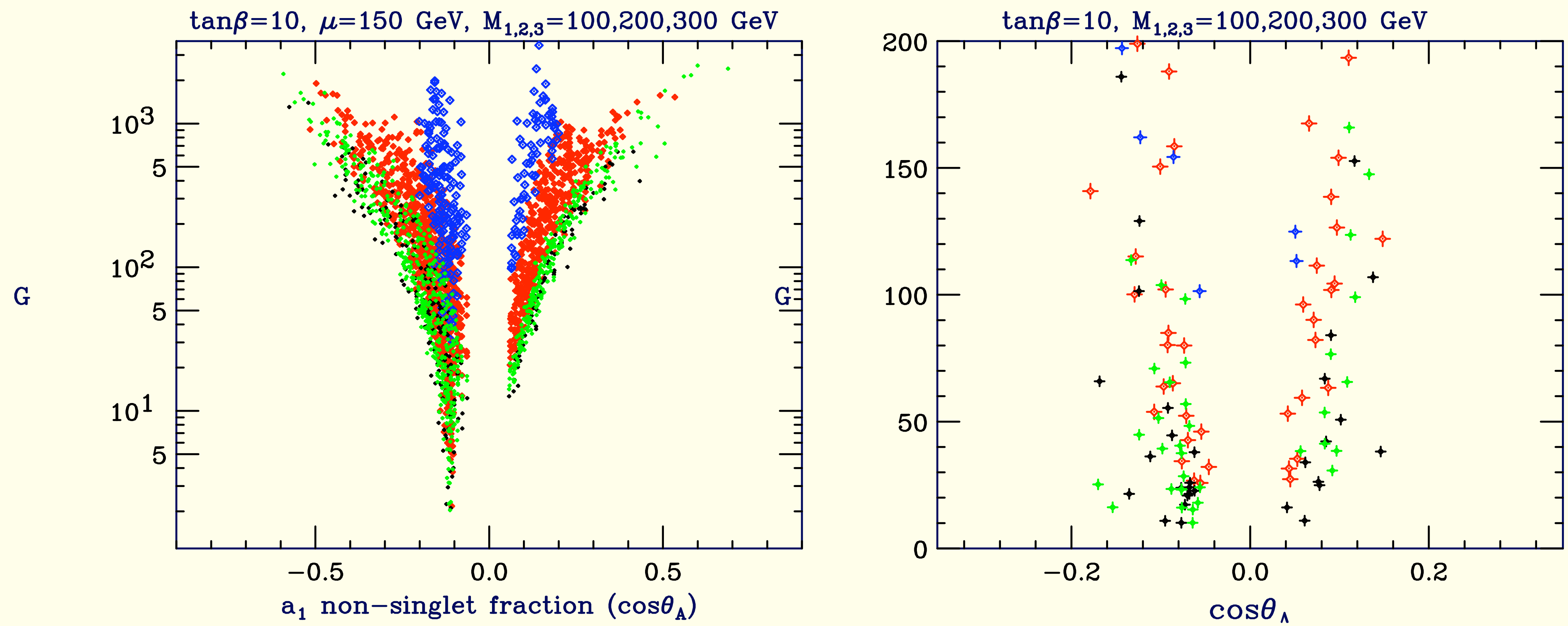


Figure 5: G vs. $\cos\theta_A$ for $M_{1,2,3} = 100, 200, 300$ GeV and $\tan\beta = 10$ from $\mu_{\rm eff} = 150$ GeV scan (left) and for points with $F < 15$ (right) having $m_{a_1} < 2m_b$ and large enough $B(h_1 \to a_1 a_1)$ to escape LEP limits. The color coding is: blue $= m_{a_1} < 2m_\tau$; red $= 2m_\tau < m_{a_1} < 7.5$ GeV; green $= 7.5$ GeV $< m_{a_1} < 8.8$ GeV; and black $= 8.8$ GeV $< m_{a_1} < 9.2$ GeV.

- In the figure, G is a measure (Dermisek+JFG: hep-ph/0611142) of the degree to which A_λ and A_κ have to be fine tuned ("light-a" fine tuning) in order to achieve required a properties of $m_a < 2m_b$ *and* $B(h \to aa) > 0.7$. The plot of G vs. $\cos\theta_A$ shows a strong preference for $m_a > 7.5~\mathrm{GeV}$ and $\cos\theta_A \lesssim 0.1$ (for $\tan\beta = 10$).

- Define a generic coupling to fermions by

$$\mathcal{L}_{af\overline{f}} \equiv iC_{af\overline{f}} \frac{ig_2 m_f}{2m_W} \overline{f}\gamma_5 f a\,, \quad \text{then} \quad C_{ab\overline{b}} = \cos\theta_A \tan\beta \qquad (15)$$

- The extracted $C_{ab\overline{b}}$ limits (JFG, arXiv:0808.2509; see also Ellwanger and Domingo, arXiv:0810.4736) are quite $\tan\beta$-independent so long as $\cos\theta_A \lesssim 0.3$.

  The extracted limits on $C_{ab\overline{b}}$ appear in Fig. 6.

- The most unconstrained region is that with $m_a > 8~\mathrm{GeV}$, especially $9~\mathrm{GeV} < m_a < 12~\mathrm{GeV}$.

  This is the same as the region with least "light-a" fine-tuning in the NMSSM.

- Need to achieve limits of $C_{ab\bar{b}} < 0.3$ to rule out the a of the $C_{ab\bar{b}} = \cos\theta_A \tan\beta \lesssim 1$ (a number which applies for $\tan\beta > 3$) scenarios preferred to achieve small light-a finetuning.

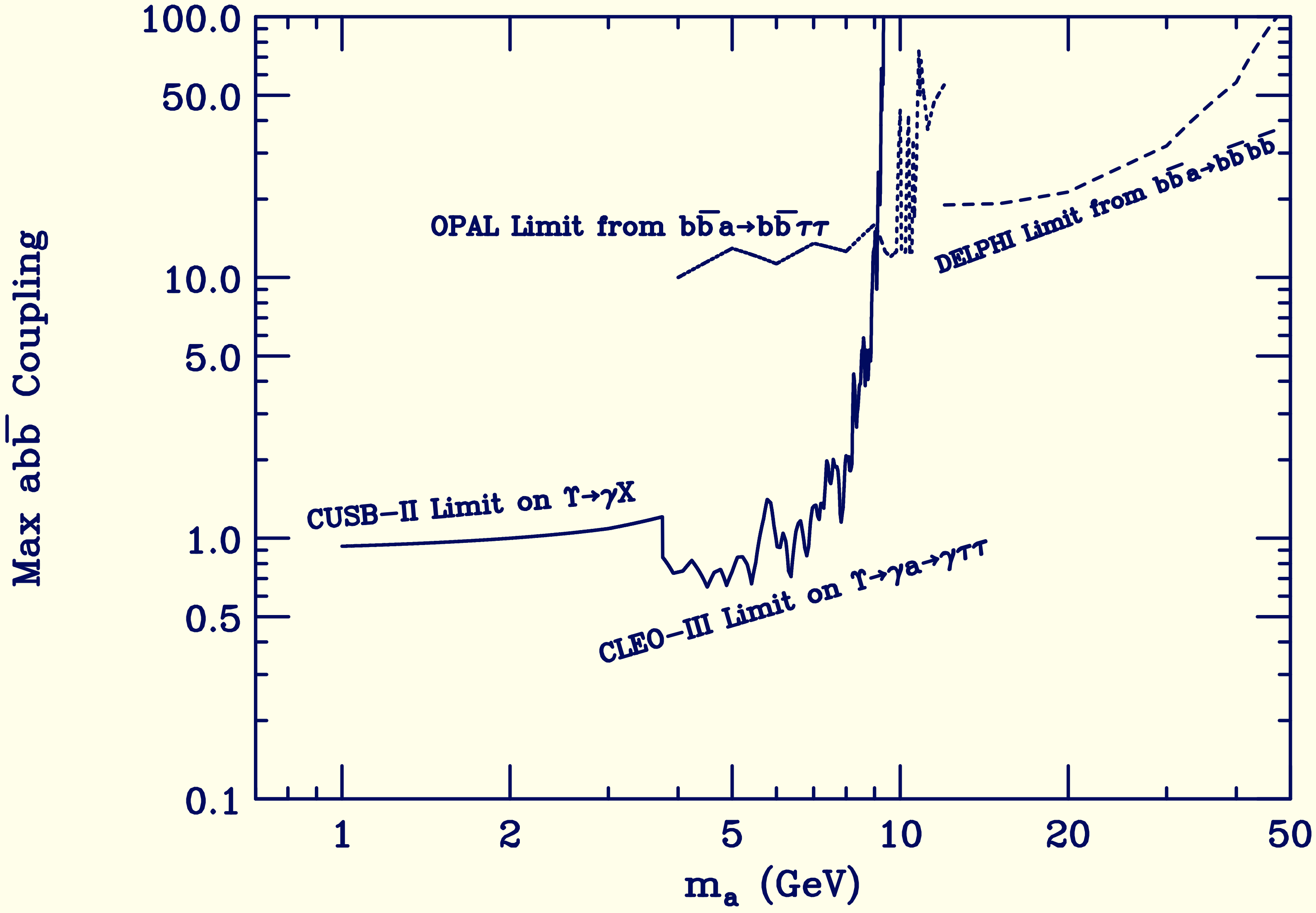


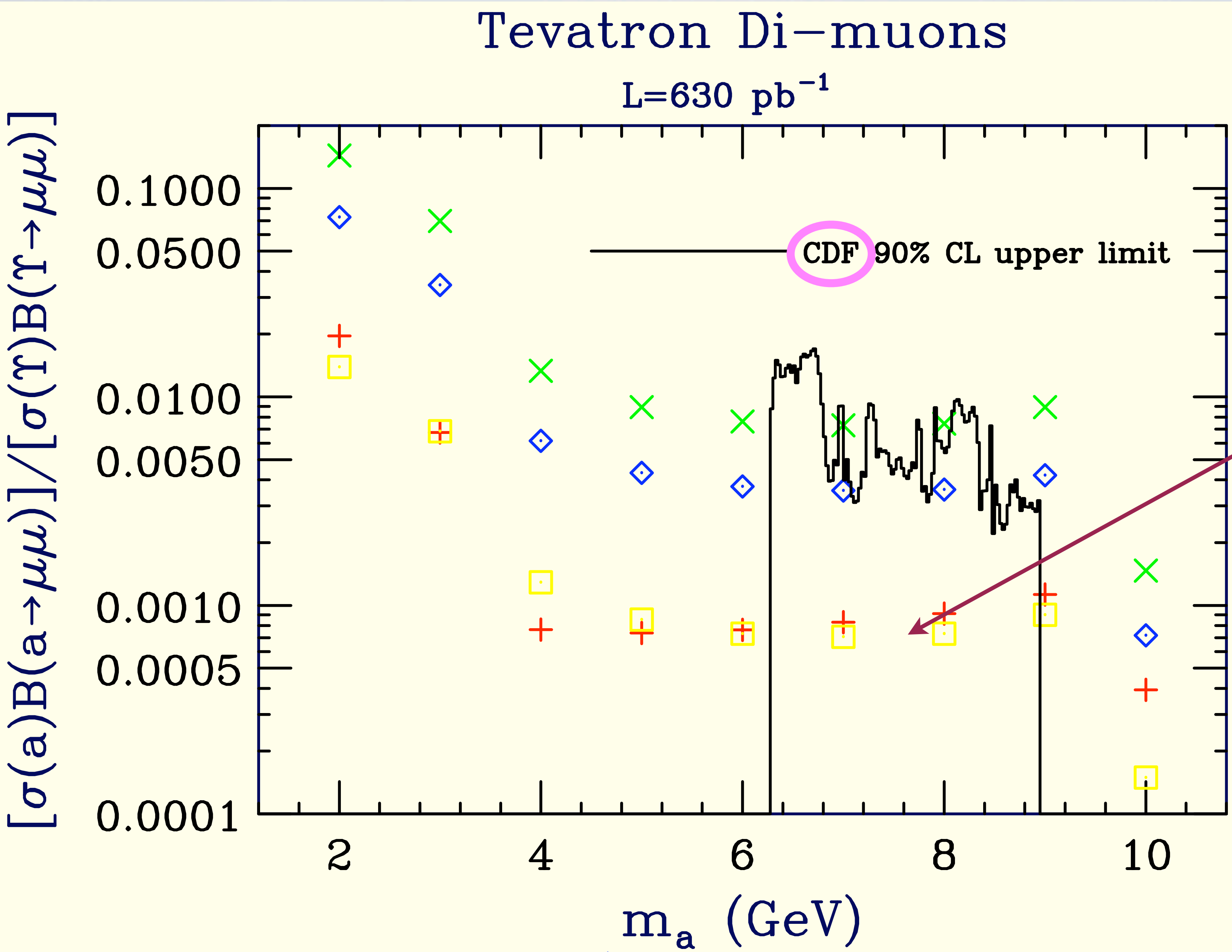
Figure 6: Limits on $C_{ab\bar{b}}$ from JFG, arXiv:0808.2509

- **In the $\sim 9~\mathrm{GeV} \lesssim m_a \lesssim 12~\mathrm{GeV}$ region only the OPAL limits are relevant.**

  Those presented depend upon how the $a \leftrightarrow \eta_b$ states mixing is modeled. A particular model (Drees+Hikasa: Phys.Rev.D41:1547,1990) is employed.

  Perhaps now that the first η_b state has been observed, this region can be better pinned down. I have not incorporated recent work by Domingo *et al.* (arXiv:0810.4736) which models this mixing in a manner consistent with the available information. In any case, models predict many η-type states in this region, not just the one that has been observed.

Actually, the Tevatron has a chance to make a valuable contribution with large integrated L.



Typical NMSSM prediction for scenarios with small "light a" fine tuning.

Figure 5: 90% CL limits on $\frac{\sigma(a)B(a\to\mu^+\mu^-)}{\sigma(\Upsilon)B(\Upsilon\to\mu^+\mu^-)}$ at small $|y|$ for $L = 630~\mathrm{pb}^{-1}$, compared to expectations for the a for $C_{ab\bar{b}} = \tan\beta = 1/C_{at\bar{t}} = 1, 2, 3$ in the 2HDM-II. Also shown (□'s) are the predictions for the NMSSM with $\tan\beta = 10$ and $\cos\theta_A = 0.1$ for which $C_{ab\bar{b}} = \tan\beta\cos\theta_A = 1$ and $C_{at\bar{t}} = \cot\beta\cos\theta_A = 1/100$ — not much different from the $C_{ab\bar{b}} = \tan\beta = 1/C_{at\bar{t}} = 1$ case.

- Translating the $630\ \mathrm{pb}^{-1}$ results into limits on $C_{ab\bar{b}}$ gives the dotted histogram in the $6-9\ \mathrm{GeV}$ region in Fig. 6 (below):

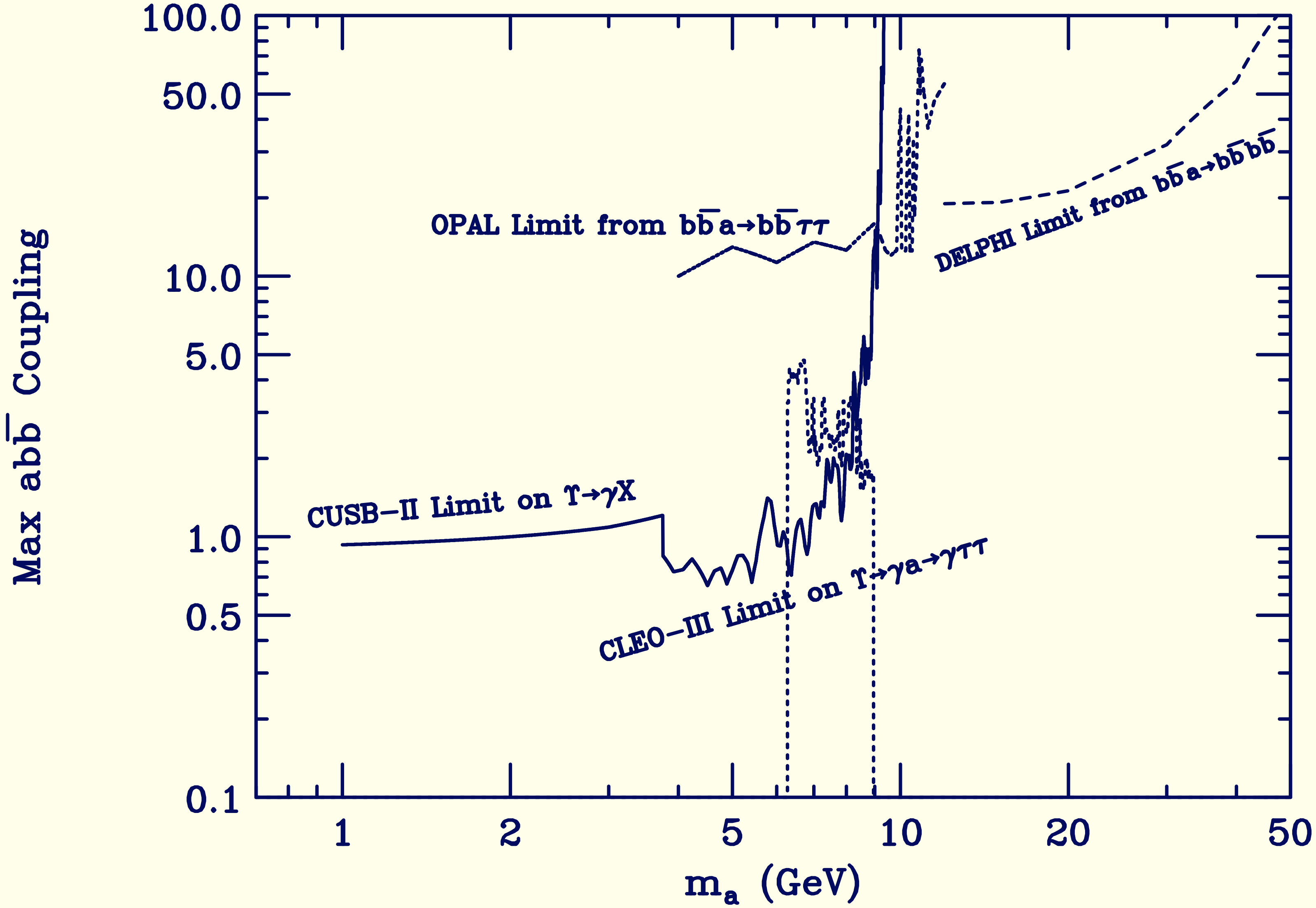


Figure 6: Limits on $C_{ab\bar{b}}$ including those from the Tevatron analysis.

The Tevatron limits are the best for $\sim 8\ \mathrm{GeV} < m_a < \sim 9\ \mathrm{GeV}$.

NMSSM models in which several, perhaps many, Higgses carry the ZZ coupling

These arise for $\tan\beta < 3$. (R. Dermisek and J. F. Gunion, arXiv:0811.3537 [hep-ph].)

- It is possible to have h_1, h_2, h^+ all light but escaping LEP and Tevatron detection by virtue of decays to a_1 with $m_{a_1} < 2m_b$.

- h_1 need not be exactly SM-like — h_2 can be light enough ($\sim 100~\mathrm{GeV}$) for precision electroweak when $g^2_{h_2WW}$ is substantial.

- Relevant scenarios arise most often for $C_{ab\bar{b}} \gtrsim 1$ especially if $\tan\beta = 2$. Current limits imply that $m_{a_1} > 7.5~\mathrm{GeV}$ is needed for $C_{ab\bar{b}} > 1$.

- The multiple LEP (and Tevatron) escapes:

  1. $B(h_1 \to a_1 a_1)$ is large, and $e^+e^- \to Zh_1 \to Za_1a_1 \to Z4\tau$ is only constrained for $m_{4\tau} < 86~\mathrm{GeV}$ (at best — lower if ZZh_1 coupling is somewhat suppressed).

2. $B(h^+ \to W^+ a_1)$ is often large, and $e^+e^- \to h^+h^- \to W^+W^-a_1a_1$ with $a_1 \to 2\tau$ was not directly searched for.
3. $B(h^+ \to \tau^+\nu)$ is often significant (but never dominant) and for cases with $m_{h^\pm}$ close to m_W, $e^+e^- \to h^+h^- \to \tau^+\tau^-2\nu_\tau$ could explain the 2.8σ deviation from lepton universality in W decays measured at LEP.
4. $B(h_2 \to a_1a_1)$ and/or $B(h_2 \to Za_1)$ are large.
   Thus, even if $e^+e^- \to Zh_2$ has large σ (which is often the case since m_{h_2} is not large), would not have seen it since the $h_2 \to Za_1$ decay was never looked for and an incomplete job was done on $h_2 \to a_1a_1 \to 4\tau$.
5. For $\tan\beta = 1.7$ it is easy to find cases where $e^+e^- \to Zh_1 \to Zb\bar{b}$ *and* $e^+e^- \to Zh_2 \to Zb\bar{b}$ would yield a substantial contribution to the LEP $0.1 \times SM$ excess near $m_{b\bar{b}} \sim 98$ GeV.
6. To observe or constrain the a_1 for these $m_{a_1} > 7.5$ GeV, large $C_{ab\bar{b}}$ scenarios will most likely require both B-factory Υ results and Tevatron high luminosity data.
7. High Tevatron L would also better limit $B(t \to h^+b)$ which at the moment is allowed up to the 40% level as these decays are included in the way CDF and D0 determine the $t\bar{t}$ cross section for the $h^+ \to W^+a_1$.

In case you hadn't noticed, we are all going crazy waiting for the Higgs?

"Unfortunately", a lot of the scenarios and theories we have developed make a lot of sense, but I remain enamored of the NMSSM Higgs scenarios and hope for eventual verification that nature has chosen "wisely".

Meanwhile, all I can do is watch and wait (but maybe not from such a close distance).

Conclusions: where is 

?

- **It is premature to claim we know where or how to find the Higgs.**
- **We could have simply missed it at LEP.**
- **There is a strong preference for a rather light Higgs boson --- PEW, SUSY+EWSB fine-tuning, ...**
- **It must decay in non-SM ways to avoid LEP limits.**
- **Many very attractive models based on SUSY allow for the needed kinds of decays.**
- **Searches for a Higgs decaying in exotic ways can be quite challenging at hadron colliders.**
- **If no Higgs is seen after a number of LHC years, is it safe to conclude that there is no Higgs?**
- **Check WW scattering (hard!).**
- **Build ILC/CLIC (2020, but Higgs detection easy once built).**
- **If the light Higgs/SUSY scenario is correct, SUSY particles should be light (as preferred by no EWSB fine tuning) and easily seen at the LHC!**