The Ideal Higgs Scenario and Experimental Probes of the Associated Light CP-Odd Higgs Boson

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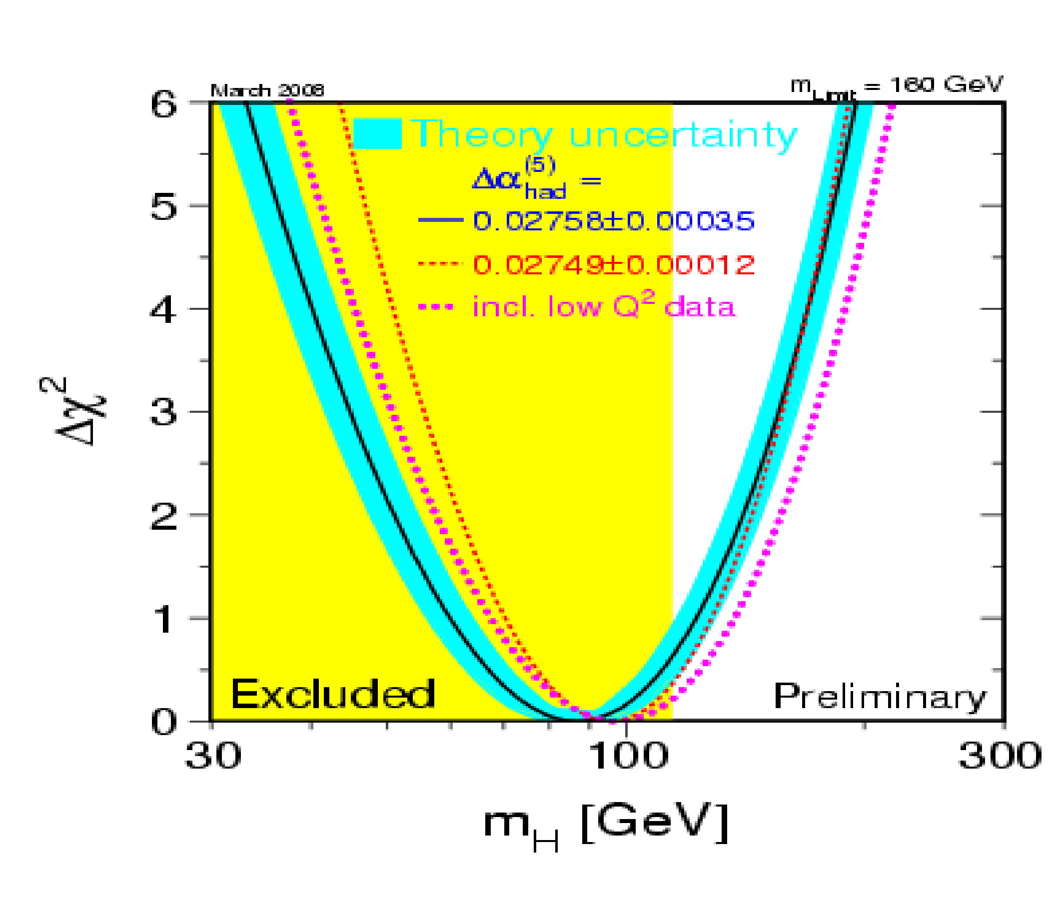
Outline

1. **The "ideal" Higgs boson motivation for a light a with $m_a < 2m_b$.**
2. **Constraints from LEP and Upsilon Decays.**
3. **Constraints from Tevatron and LHC.**
4. **Relation to a_μ.**
5. **The NMSSM Context.**

Criteria for an ideal Higgs theory

- **The theory should predict a Higgs with SM coupling-squared to WW, ZZ and with mass in the range preferred by precision electroweak data. The latest plot is:**



At 95% CL, $m_{h_{\rm SM}} < 160~{\rm GeV}$ and the $\Delta\chi^2$ minimum is near $85~{\rm GeV}$ when all data are included.

The latest m_W and m_t measurements also prefer $m_{h_{\rm SM}} \sim 100~{\rm GeV}$.

The blue-band plot may be misleading due to the discrepancy between the "leptonic" and "hadronic" measurements of $\sin^2\theta_W^{eff}$, which yield $\sin^2\theta_W^{eff} = 0.23113(21)$ and $\sin^2\theta_W^{eff} = 0.23222(27)$, respectively. The SM has a CL of only 0.14 when all data are included.

If only the leptonic $\sin^2\theta_W^{eff}$ measurements are included, the SM gives a fit with CL near 0.78. However, the central value of $m_{h_{\rm SM}}$ is then near $50~{\rm GeV}$ with a 95% CL upper limit of $\sim 105~{\rm GeV}$ (Chanowitz, xarXiv:0806.0890).

- Thus, in an ideal model, a Higgs with SM-like ZZ coupling should have mass no larger than $105~{\rm GeV}$. Our generic notation will be H.

  But, at the same time, It should avoid the LEP limits on such a light Higgs. One generic possibility is for its decays to be non-SM-like.

Table 1: LEP m_H Limits for a H with SM-like ZZ coupling, but varying decays.

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

To have $m_H \leq 105~\mathrm{GeV}$ requires one of the final three modes.

- **Of course, one can also escape the LEP limit by have going to multi-doublet Higgs models and having reduced HZZ coupling for the lightest Higgs boson.**

  However, escaping the LEP limit then requires that the heavier Higgs boson that carries the rest of the ZZ coupling have mass above some lower bound which will be not far below $115~\mathrm{GeV}$.

  This scenario will then have poorer consistency with precision electroweak data than having a single light H with extra decays.

- **Perhaps the ideal Higgs should be such as to predict the 2.3σ excess at $M_{b\bar{b}} \sim 98~\mathrm{GeV}$ seen in the $Z + b\bar{b}$ final state.**

  The simplest possibility for explaining the excess is to have $m_H \sim 100~\mathrm{GeV}$ and $B(H \to b\bar{b}) \sim 0.1 B(H \to b\bar{b})_{SM}$ (assuming H has SM ZZ coupling).

- **All of this can be accomplished in the NMSSM with no fine-tuning, ..., but for now I wish to be more general and only look at the generic possibility of suppressing the $H \to b\bar{b}$ branching ratio by having a light a ($m_a < 2m_b$ to avoid LEP $Z + b's$ limits) with $B(H \to aa) > 0.7$.**

  This is easy to achieve in general 2HDM-II models, but is not possible in the MSSM.

  It is a very natural possibility in the NMSSM where a light a corresponds to a $U(1)_R$ symmetry limit.

Constraints on a from LEP and Upsilon Decays

To fit with the Ideal Higgs scenario, we are especially interested in an a with $m_a < 2m_b$.

- Of particular importance are the constraints on $C_{ab\overline{b}}$, where the generic $C_{af\overline{f}}$ is defined by

$$\mathcal{L}_{af\overline{f}} \equiv iC_{af\overline{f}} \frac{ig_2 m_f}{2m_W} \overline{f} \gamma_5 f a \,. \tag{1}$$

We will only discuss models in which $C_{ab\overline{b}} = C_{a\mu^-\mu^+}$. (To escape, requires 3 or more doublets.)

The most useful current limits on $C_{ab\overline{b}}$ for a light a come from CUSB-II (old 90% CL) limits on $B(\Upsilon \to \gamma X)$ (where X is assumed to be visible), recent CLEO-III limits on $B(\Upsilon \to \gamma a)$ assuming $a \to 2\tau$, OPAL limits on $e^+e^- \to b\overline{b}a \to b\overline{b}2\tau$ and DELPHI limits on $e^+e^- \to b\overline{b}a \to b\overline{b}b\overline{b}$.

(The Tevatron limits on $b\overline{b}a \to b\overline{b}2\tau$ apply for quite high m_a, beyond the region we wish to focus on.)

The CLEO-III limits are now particularly strong.

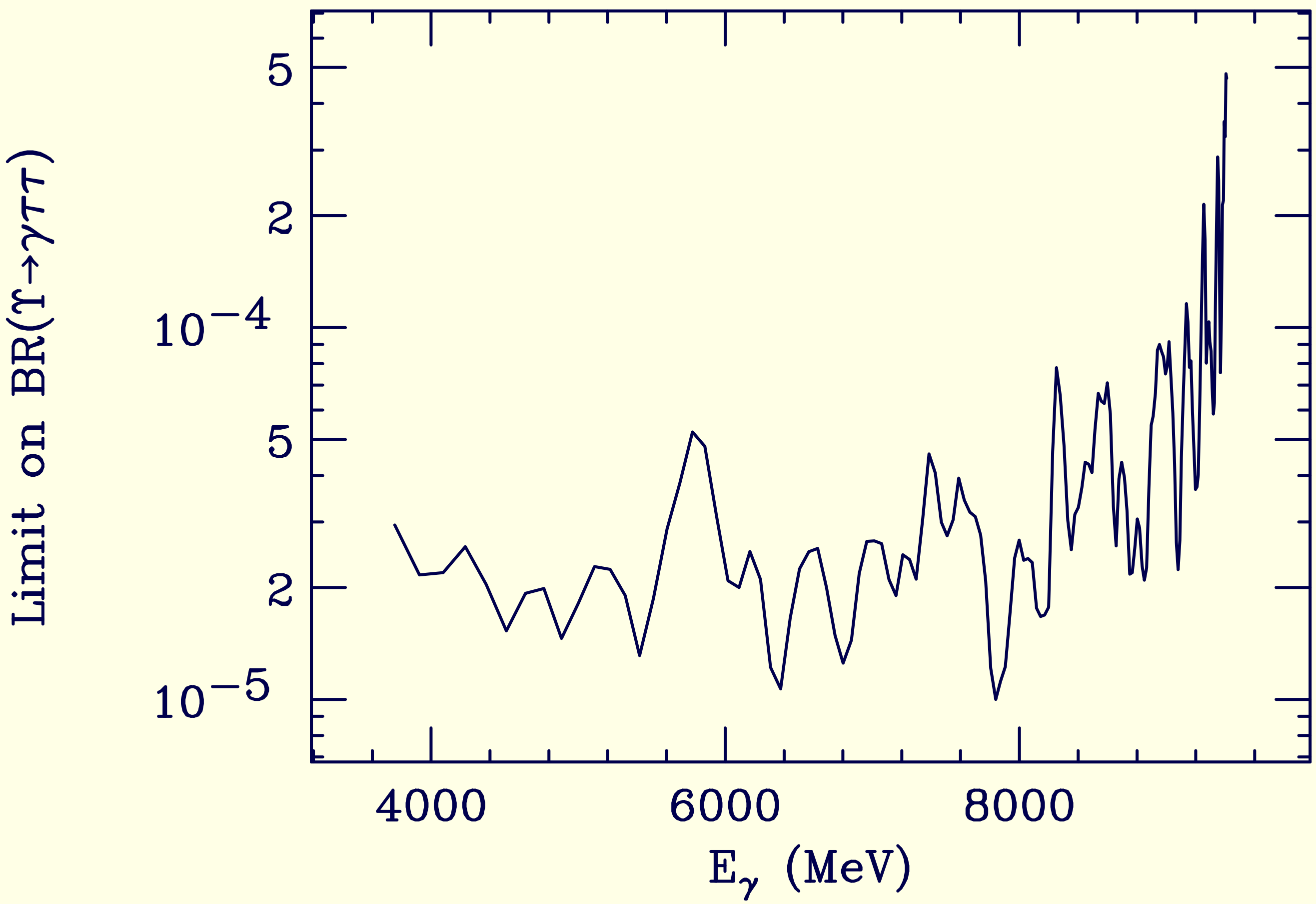


Figure 1: **Limits on $B(\Upsilon \to \gamma\tau^+\tau^-)$.**

- **For the most part the extracted $C_{ab\bar{b}}$ limits (JFG, arXiv:0808.2509) are quite model-independent other than weak dependence on up-quark couplings (mostly top in gg coupling loop) through $B(a \to \tau\tau)$ and $B(a \to b\bar{b})$. The extracted limits appear in Fig. 2,**

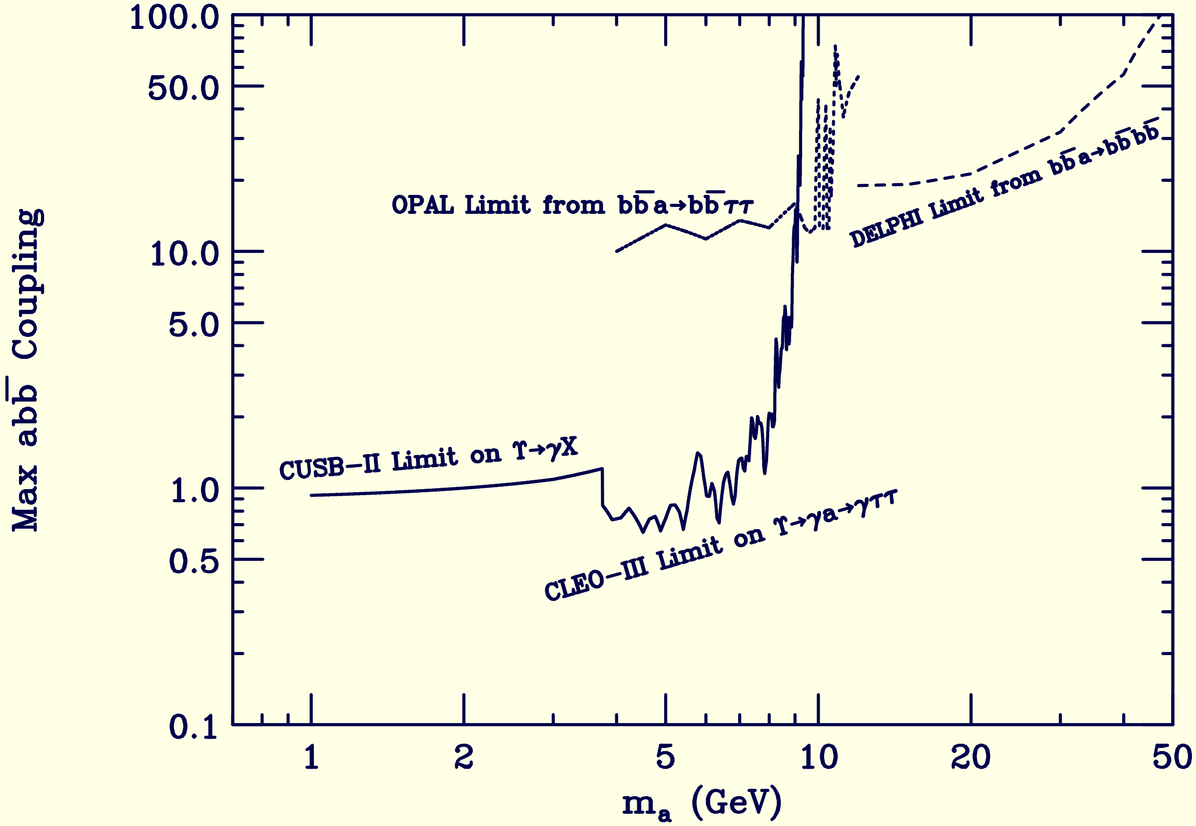


Figure 2: Limits on $C_{ab\bar{b}}$.

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

In the $\sim 9 \text{ GeV} \lesssim m_a \lesssim 12 \text{ GeV}$ region only the OPAL limits are relevant.

Those presented depend upon how the $a \leftrightarrow \eta_b$ states mixing is modeled. A particular model is employed, but there has been little recent work on this.

Perhaps now that the first η_b state has been observed, this region can be better pinned down.

Constraints from Tevatron and LHC

- **However, we (JFG+Dermisek) have recently discovered that Tevatron data on the di-muon spectrum also has an impact.**

  In particular, a recent CDF analysis has been directly employed to place a 90% CL upper limit on $\sigma(\epsilon) \times B(\epsilon \to \mu^+\mu^-)$, where the ϵ is some narrow resonance, relative to the measured $\sigma(\Upsilon) \times B(\Upsilon \to \mu^+\mu^-)$.

  The histogram shown in the following figure is the CDF $630~\mathrm{pb}^{-1}$ result.

  In the figure, the predictions for the cross section ratio for the a are: red crosses=$\tan\beta = 1$, blue diamonds=$\tan\beta = 2$, green crosses=$\tan\beta = 3$. Fortunately, the a and Υ cross sections are quite flat in y and only small $|y|$ production is kept in the experimental analysis.

  The a predictions employ the HIGLU program of Spira, Djouadi etal and agree with my own independent program.

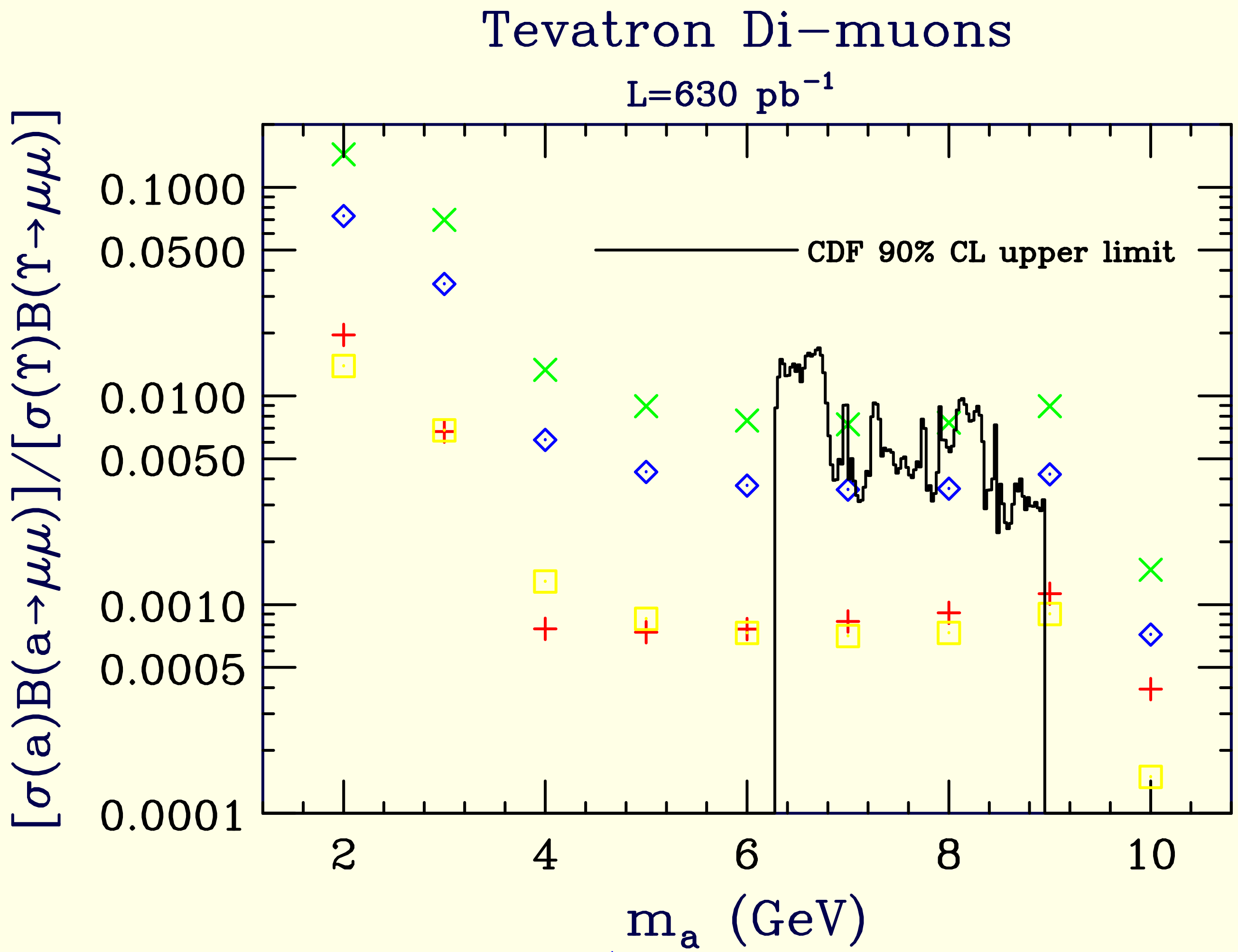


Figure 3: 90% CL limits on $\frac{\sigma(a)B(a\to\mu^+\mu^-)}{\sigma(\Upsilon)B(\Upsilon\to\mu^+\mu^-)}$ at small $|y|$ for $L = 630~\mathrm{pb}^{-1}$, compared to expectations for the a.

Why CDF stopped at $9~\mathrm{GeV}$ is not clear to me. It would certainly be very useful to at least go all the way to $B\overline{B}$ threshold (and perhaps a bit beyond since the complexity of the threshold region is such that the LEP limits on a light $h \to aa$ might still be obeyed for m_a somewhat above threshold).

Of course, as more integrated luminosity is accumulated, limits will improve.

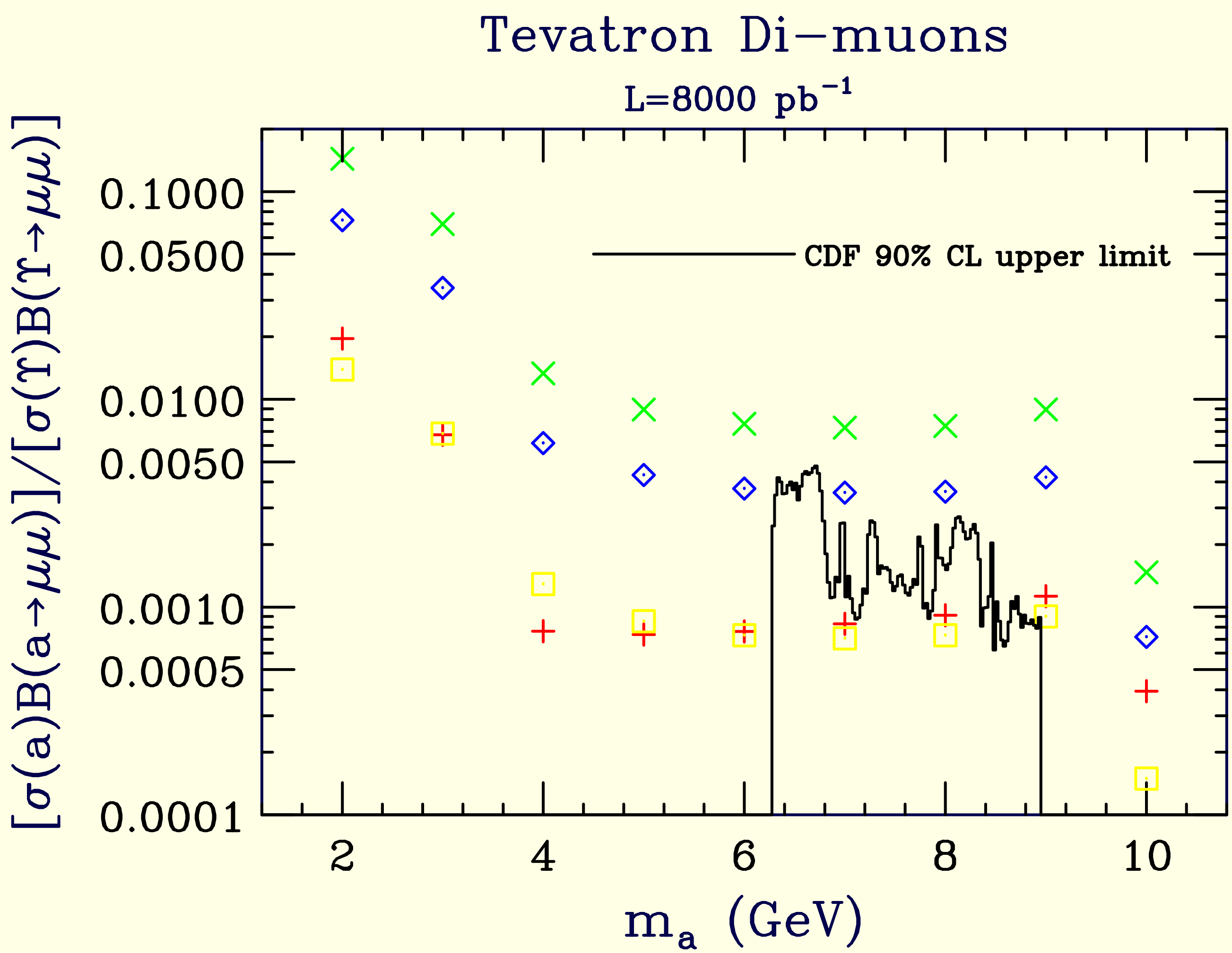


Figure 4: **90% CL limits on** $\frac{\sigma(a)B(a\to\mu^+\mu^-)}{\sigma(\Upsilon)B(\Upsilon\to\mu^+\mu^-)}$ **at small** $|y|$ **for** $L = 8\ \mathrm{fb}^{-1}$.

- **Now use interpolation to turn the $630\ \mathrm{pb}^{-1}$ limits into limits on $C_{ab\bar{b}}$.**

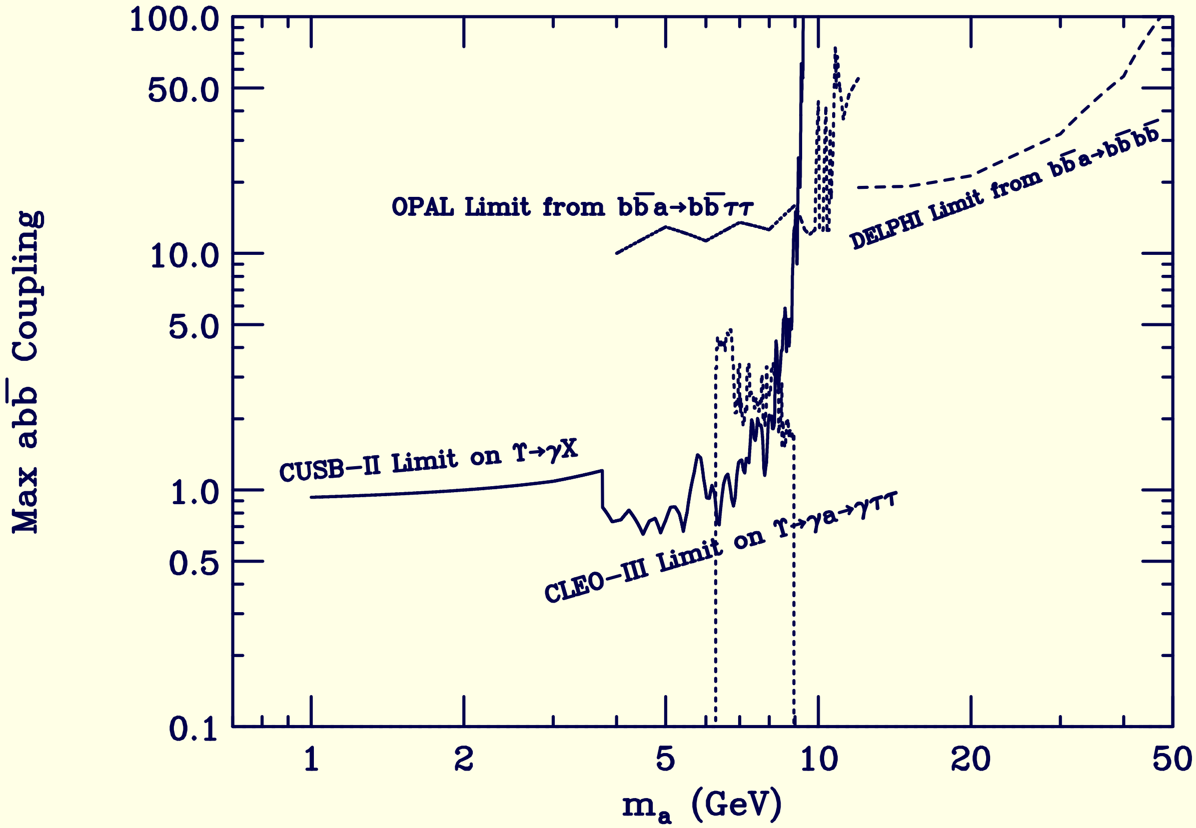


Figure 5: **Limits on $C_{ab\bar{b}}$ including those from the Tevatron analysis.**

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

There is one caveat. In the CDF analysis, the μ's are required to be

isolated. Radiative corrections include some g radiation diagrams. The extent to which this would cause the μ's to not be isolated would require a detailed MC. If you keep only virtual NLO diagrams, then the $K \sim 2.5$ factor for full NLO declines to about $K \sim 2$ and limits are a bit weaker.

- What about the LHC?

  This requires work. New issues include:

  1. Triggering on soft muons.
     Probably a recoiling jet is required to boost the μ momenta.
  2. $b\overline{b}$ backgrounds will be bigger than at the Tevatron.
  3. Muon isolation is clearly trickier, especially at higher luminosity.
  4. Interestingly, early low $\mathcal{L}$ running might provide the optimal situation since you can simply take all data and then work on it.
     An interesting plot from ICHEP is shown below.

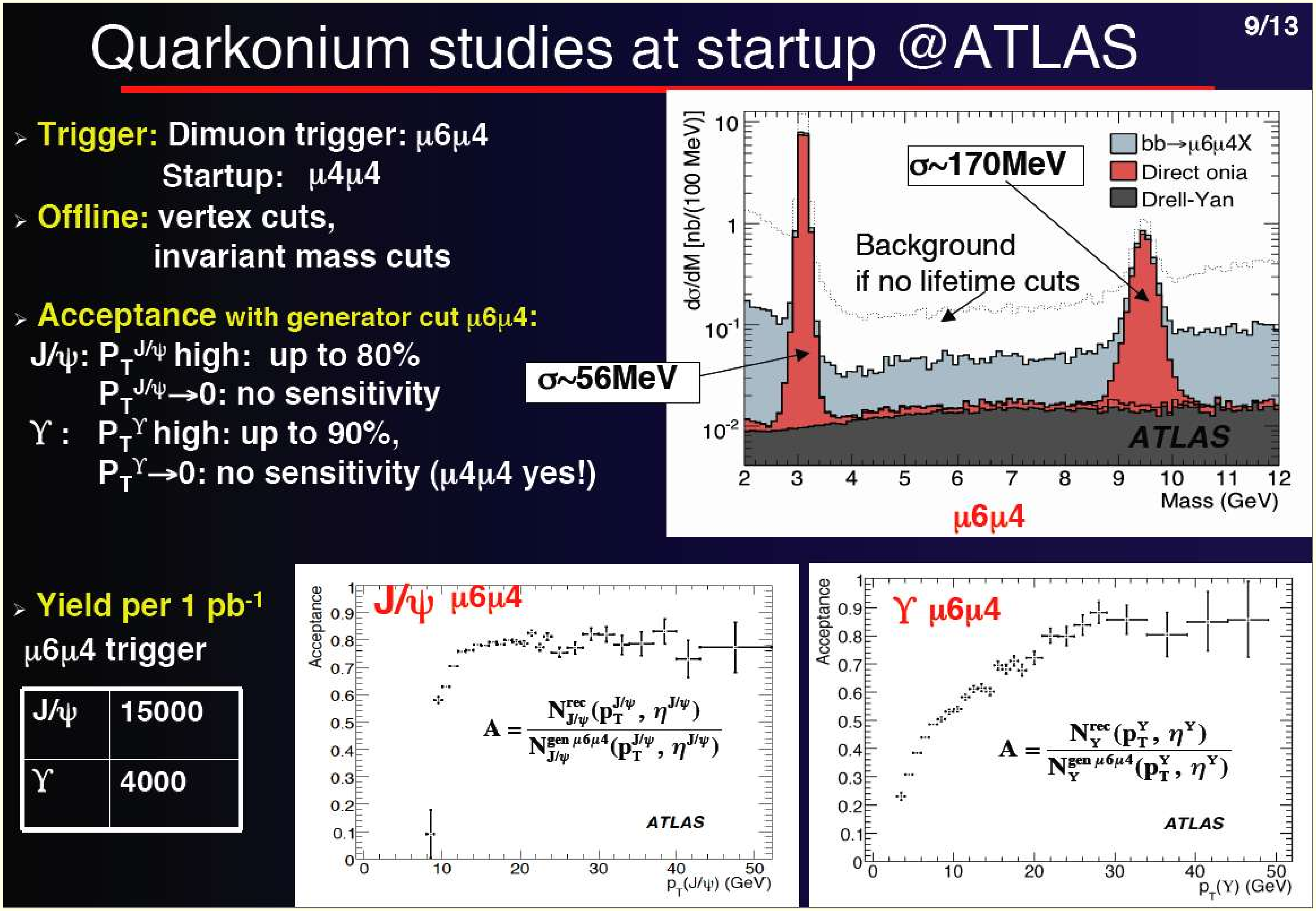


Figure 6: LHC di-muon slide from ICHEP.

After cuts (including requiring high p_T for the di-muon pair) the study finds about $4000\ \Upsilon$ events for each $L = 1\ \mathrm{pb}^{-1}$. Early running at low L will probably give about $100\ \mathrm{pb}^{-1}$ (Jeffrey Berryhill's talk at recent LHC FNAL workshop), implying about $400,000$ LHC events.

For $630\ \mathrm{pb}^{-1}$, the CDF analysis retained $52,700\ \Upsilon$ events. For $8\ \mathrm{fb}^{-1}$ one gets $669,206$ events (assuming simple L scaling), and so it is not clear if LHC will do better given that their criteria retain some $b\bar{b}$ background in addition to the Drell-Yan events that are the only Tevatron background.

5. Can CMS find a way to do low mass di-muons when running at high $\mathcal{L}$? Well, of course you can reduce your trigger rate by requiring large p_T, but backgrounds might become more insidious.
6. Could LHCb do better?

Implications for a_μ

- Let us accept the current limits on $C_{ab\bar{b}}$.

- An interesting question is whether there is any possibility that a light a could be responsible for the observed a_μ discrepancy which is of order $\Delta a_\mu \sim 30 \times 10^{-10}$.

- The maximum possible value of δa_μ from the a, corresponding to the maximum allowed $C_{ab\bar{b}}$, as a function of m_a for fixed values of $R^2_{b/t} = C_{ab\bar{b}}/C_{at\bar{t}}$ and for the 2HDM-II $R^2_{b/t} = \tan^2\beta$ case are shown in Fig. 7.

  One sees that it is quite improbable that a light a could explain Δa_μ.

  Only in the small window in m_a from about $8~\mathrm{GeV}$ ($9.5~\mathrm{GeV}$ for 2HDM-II) up to $\sim 12~\mathrm{GeV}$, where $C_{ab\bar{b}}$ limits are the weakest ($C_{ab\bar{b}} \lesssim 15 - 60$), might it be possible.

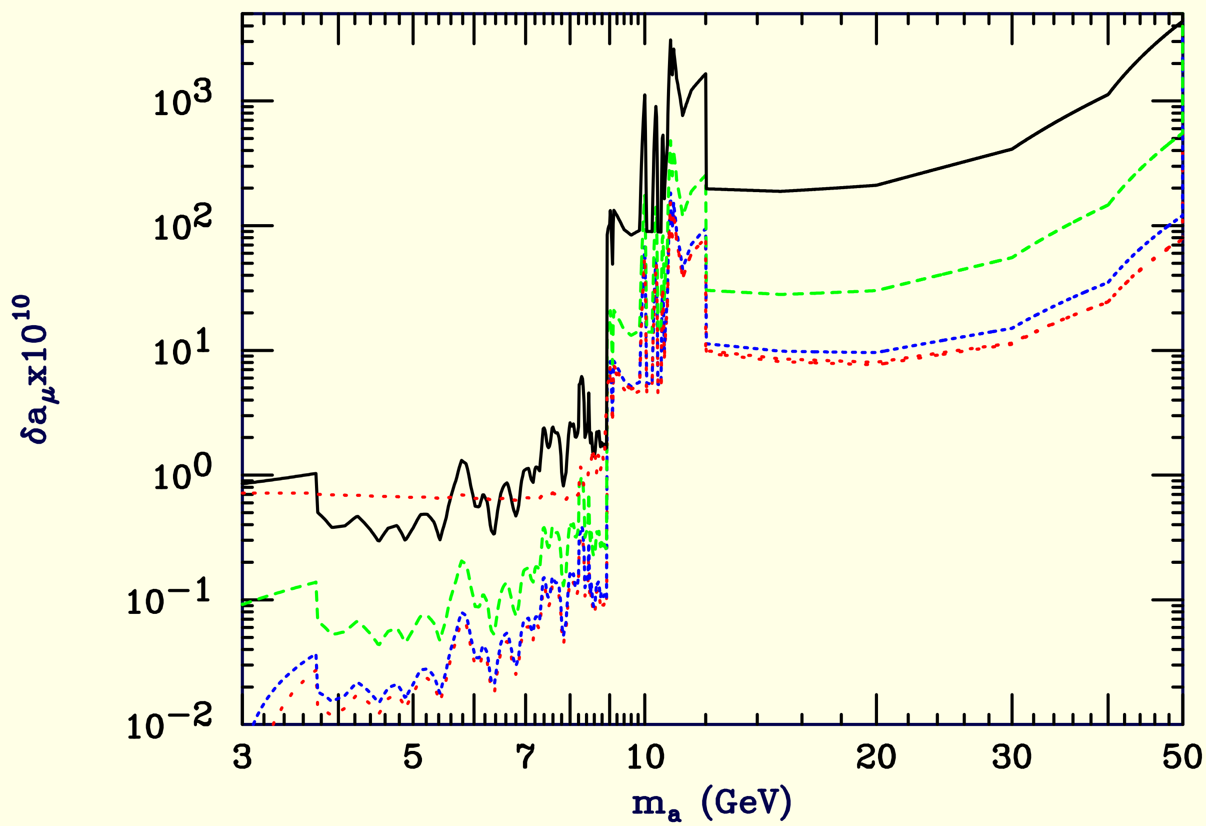


Figure 7: Results for $\delta a_\mu^{\max}$ from a CP-odd a for various $R_{b/t}^2 = C_{ab\bar b}/C_{at\bar t}$ models are plotted after incorporating the $C_{ab\bar b}$ experimental limits. Curves are for $R_{b/t} = 1, 3, 10, 50$ and for the 2HDM-II prediction of $R_{b/t} = \tan\beta$ (which looks like $R_{b/t} = 50$ for $m_a \gtrsim 9$ GeV and is the isolated red curve at lower m_a.)

Note: smaller $R_{b/t}$ allows bigger δa_μ since for given $C_{ab\bar b}$ the larger $C_{at\bar t} = C_{ab\bar b}/R_{b/t}^2$ is, the larger will be the top-loop contribution to δa_μ.

The NMSSM Context

Recall (JFG+Dermisek):

- As reviewed yesterday, the NMSSM provides a beautiful solution to the μ problem since all dimensionful quantities are set by the scale of supersymmetry breaking (which must be $\lesssim 1$ TeV in order to avoid fine-tuning in order to get a Higgs mass-squared that is in the right balk park). One gets $\mu \sim \lambda\langle S\rangle$. Here, the superpotential and relevant V_{soft} terms are:

$$W \ni \lambda \widehat{S}\widehat{H}_u\widehat{H}_d + \frac{\kappa}{3}\widehat{S}^3 \quad V_{soft} \ni \lambda A_\lambda S H_u H_d + \frac{\kappa}{3}A_\kappa S^3 \,. \tag{2}$$

- In any supersymmetric model, the value of m_Z^2 is least sensitive to the GUT-scale parameters if the stops have $m_{\widetilde t} \lesssim 350$ GeV and that for such stop masses one will typically find that $m_{h_1} \lesssim 100$ GeV (for $\tan\beta > 3$ — we return to lower $\tan\beta$ in a moment).

- The NMSSM is the simplest supersymmetric model that preserves all the good properties of the MSSM (coupling constant unification and RGE generation of EWSB) for which a light ($m_{h_1} < 105~\mathrm{GeV}$) Higgs boson with SM-like ZZ coupling (perfect for electroweak precision data) can escape LEP limits.

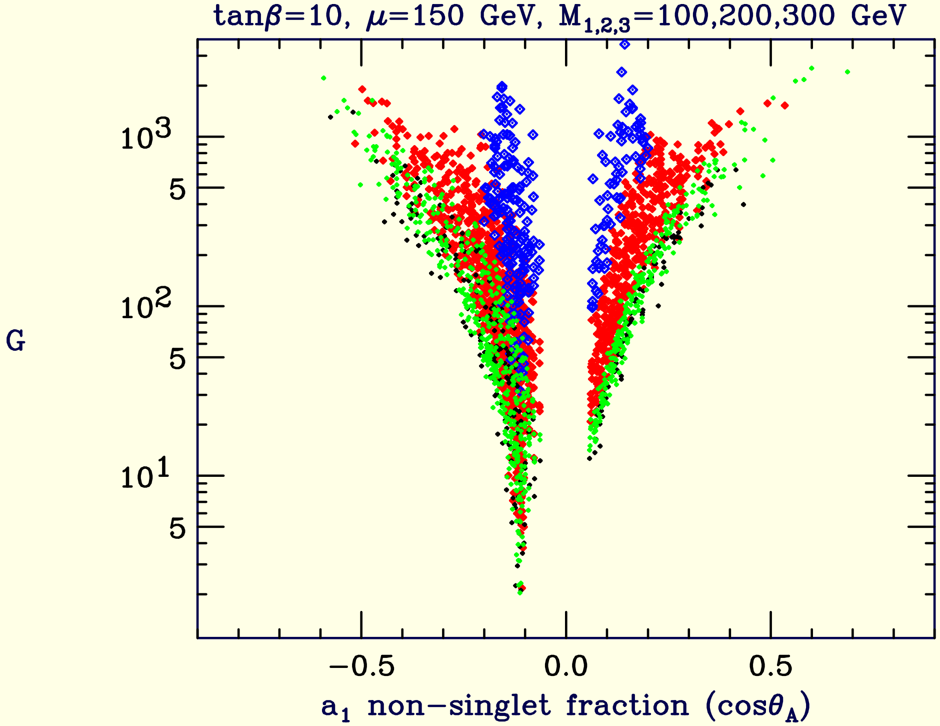
  The h_1 escapes LEP limits if $h_1 \to a_1 a_1$ is large and $m_{a_1} < 2m_b$.

- In the NMSSM context, a phenomenologically important quantity is $\cos\theta_A$, the coefficient of the MSSM-like doublet Higgs component of the a_1:

$$a_1 = \cos\theta_A A_{MSSM} + \sin\theta_A A_S \,. \tag{3}$$

- Starting from GUT-scale parameters A_λ and A_κ close to zero (the $U(1)_R$ symmetry limit) and evolving gives low-scale A_λ and A_κ values that will typically yield a light a_1.

- Still, to achieve $B(h_1 \to a_1 a_1) > 0.7$ for $m_{a_1} < 2m_b$ can require some fine-tuning. A measure is G.



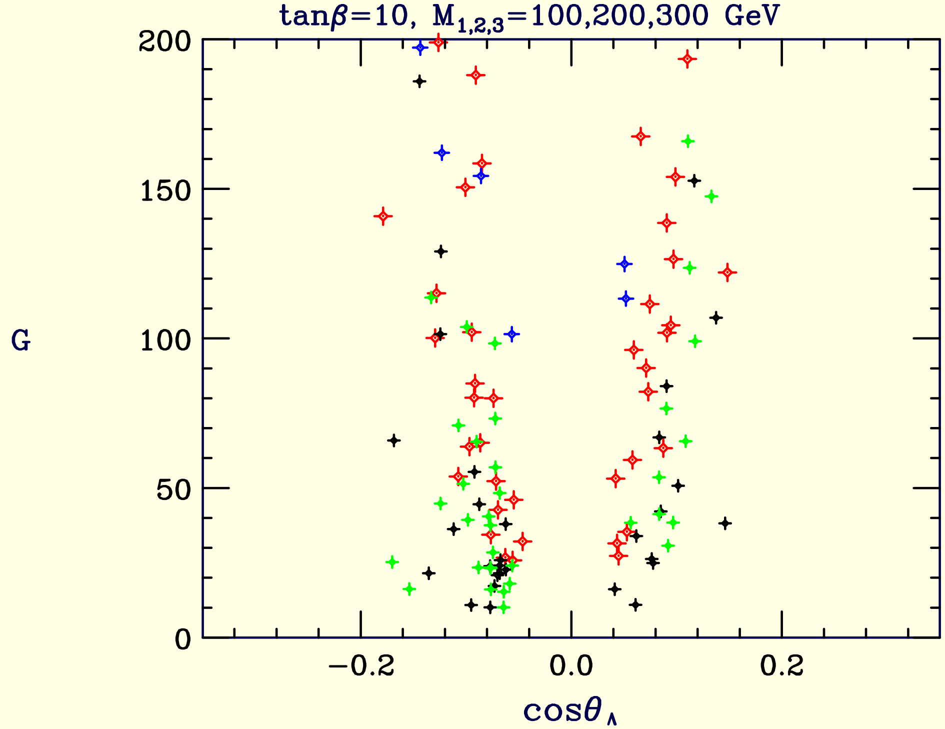


Figure 8: G vs. $\cos\theta_A$ for $M_{1,2,3} = 100, 200, 300$ GeV and $\tan\beta = 10$ from $\mu_{\rm eff} = 150$ GeV scan (left) and for points with $F < 15$ (right) having $m_{a_1} < 2m_b$ and large enough $B(h_1 \to a_1 a_1)$ to escape LEP limits. The color coding is: blue $= m_{a_1} < 2m_\tau$; 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.

Note:

1. The blue $+$'s, which are the points with $m_{a_1} < 2m_\tau$, have rather large G; in particular, they require precise tuning of A_λ and A_κ (the relevant soft parameters) at scale M_U.
2. Really small G occurs for $m_{a_1} > 7.5~\mathrm{GeV}$ and $\cos\theta_A \sim -0.1$ (for $\tan\beta = 10$).
   The smallest G scenarios then have
   $$C_{ab\bar{b}} \sim \cos\theta_A \tan\beta \sim -1. \tag{4}$$
3. This value of $C_{ab\bar{b}}$ for the small-G scenarios applies for all $\tan\beta > 3$ (we return to smaller $\tan\beta$ shortly).
4. Also, note that there is a lower bound on $|\cos\theta_A|$, see Fig. 8. It arises because $B(h_1 \to a_1 a_1)$ falls below 0.75 for too small $|\cos\theta_A|$.
   As a result, $C_{ab\bar{b}}$ can never be too far below 1.
5. A convenient way to visualize the impact of experimental constraints in the NMSSM case is to plot the maximum value of $\cos\theta_A$ that is allowed as a function of m_{a_1} for various fixed $\tan\beta$ values.
   As we have seen, $7.5~\mathrm{GeV} < m_{a_1} < 2m_b$ is poorly constrained by Υ decays, but the Tevatron provides some constraints up to $9~\mathrm{GeV}$,

hopefully extendable with further analysis to higher m_{a_1}.

The result is Fig. 9.

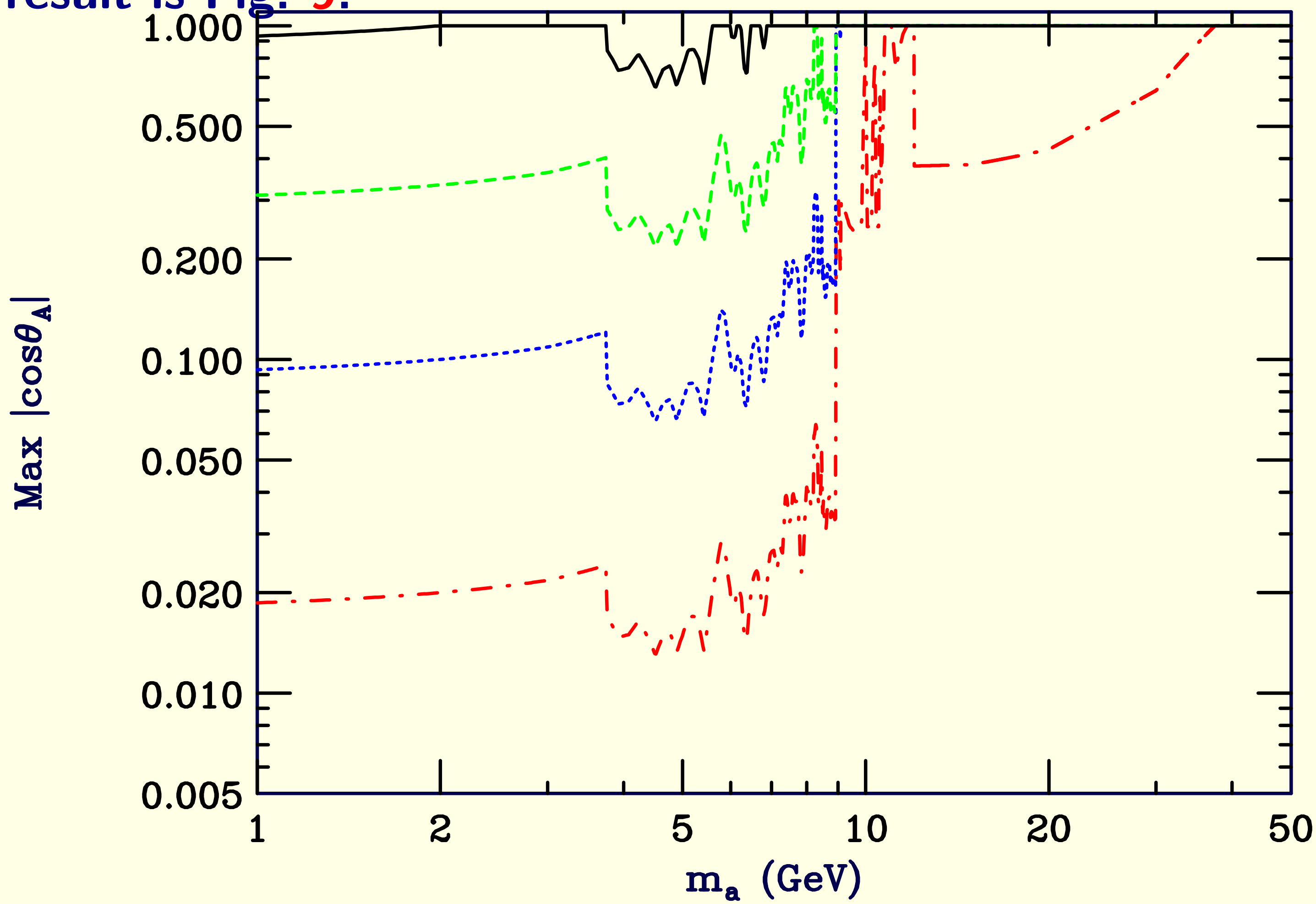


Figure 9: The experimental limits on the maximum value of $|\cos\theta_A|$ as a function of m_{a_1} for $\tan\beta = 1, 3, 10, 50$, including the Tevatron $630~\mathrm{pb}^{-1}$ limits.

Looking at the $\tan\beta = 10$ (blue) curve, you will see that $|\cos\theta_A^{\max}|$ is not that far above the small-G value of ~ 0.1 for $m_{a_1} > 7.5~\mathrm{GeV}$.

6. **The a_1 of the NMSSM Ideal Higgs scenario might in fact be observed if Υ decays and the Tevatron di-muon spectrum can both be pushed to the $|C_{ab\bar b}| < 1$ level in the $7.5~\mathrm{GeV} \lesssim m_{a_1} \lesssim 10-11~\mathrm{GeV}$ region.**

Typically one must gain a factor of 2 to 3 improvement in $|\cos\theta_A^{\max}|$ relative to current limits, which statistically means a factor of about 10 in luminosity. Of course, the data fluctuations will undoubtedly not be in the same location in the larger data set.

If we simply scale the $630~\mathrm{pb}^{-1}$ Tevatron data to $8~\mathrm{fb}^{-1}$, the projected limits relative to the $\tan\beta = 10$, $C_{ab\bar b} = \tan\beta\cos\theta_A = -1$ NMSSM cross section prediction are shown Fig. 10 (a repeat of Fig. 4). One is starting to probe the $|C_{ab\bar b}| \sim 1$ small-G-preferred level.

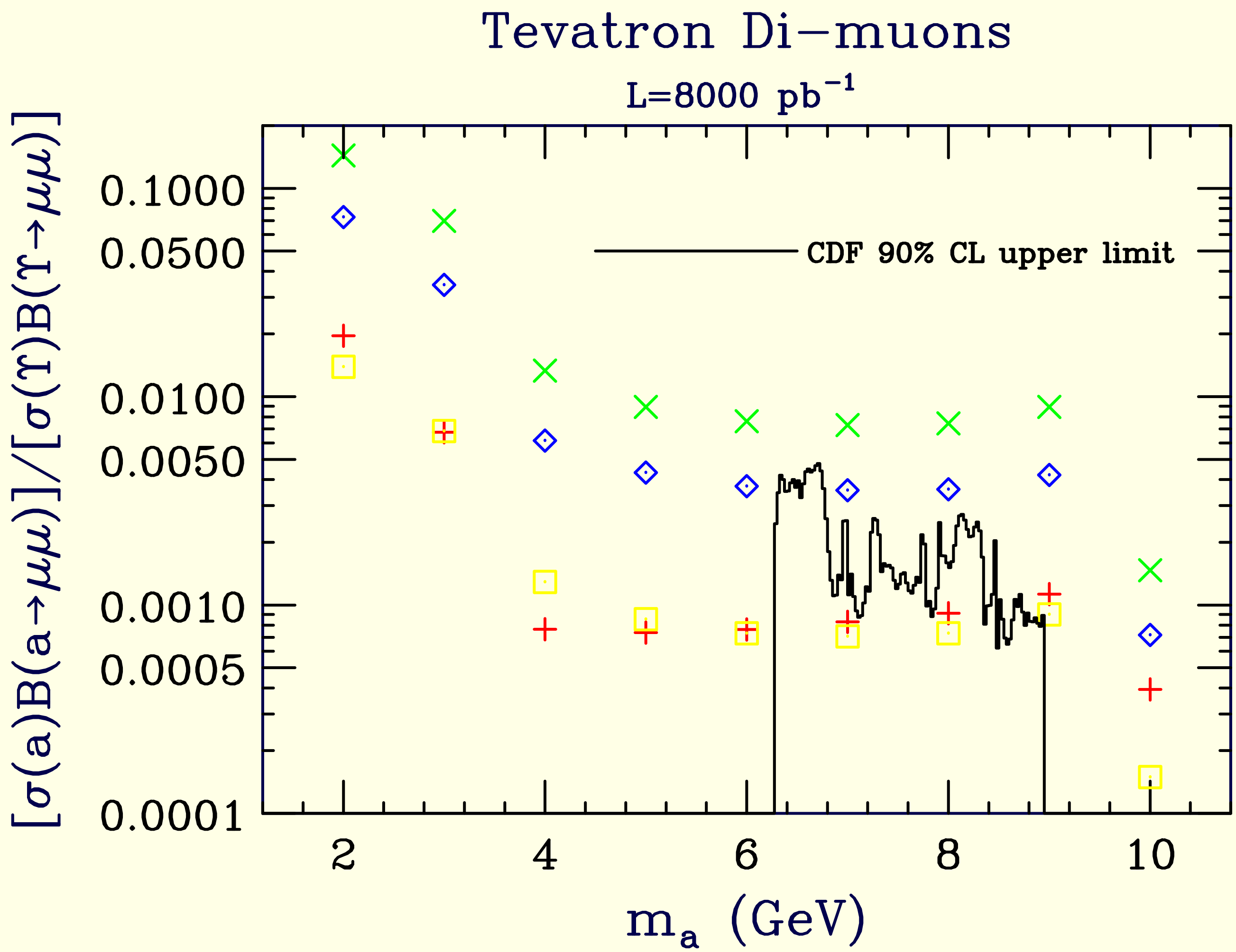


Figure 10: **90% CL limits on $\frac{\sigma(a)B(a\to\mu^+\mu^-)}{\sigma(\Upsilon)B(\Upsilon\to\mu^+\mu^-)}$ at small $|y|$ for $L = 8~\text{fb}^{-1}$. Yellow squares are the NMSSM predictions for $\tan\beta = 10$ and $C_{ab\bar{b}} = \tan\beta\cos\theta_A = -1$.**

(Small changes relative to the red pluses of $\tan\beta = 1$ occur because of re-weighting of the top loop in $gg \to a$ fusion.)

Of course, if $K \sim 2$ vs. the $K \sim 2.5$ used in the plot applies then the constraint is more marginal.

Hopefully, D0 will weigh in with a result that can be combined with CDF. And, hopefully, both will extend their results above $9~\mathrm{GeV}$ to cover all the way up to $m_{a_1} = 2m_B$ and somewhat above, thereby completely covering the region for which an ideal Higgs scenario is possible and above that which Υ decays can never access.

- Interesting new $\tan\beta \leq 2$ NMSSM scenarios with $m_{a_1} < 2m_b$.

It is possible to have h_1, h_2, h^+ all light but escape LEP and Tevatron detection by virtue of unusual decays. Such scenarios arise most often if $\cos^2\theta_A > 0.5$, especially if $\tan\beta = 2$. Current limits on $\cos^2\theta_A$ imply that $m_{a_1} > 7.5~\mathrm{GeV}$ is need to have this large a value of $\cos^2\theta_A$.

$\Rightarrow$ need improved Tevatron limits on Drell-Yan $gg \to a_1 \to \mu^+\mu^-$.

Below we show some $\tan\beta = 2$ results.

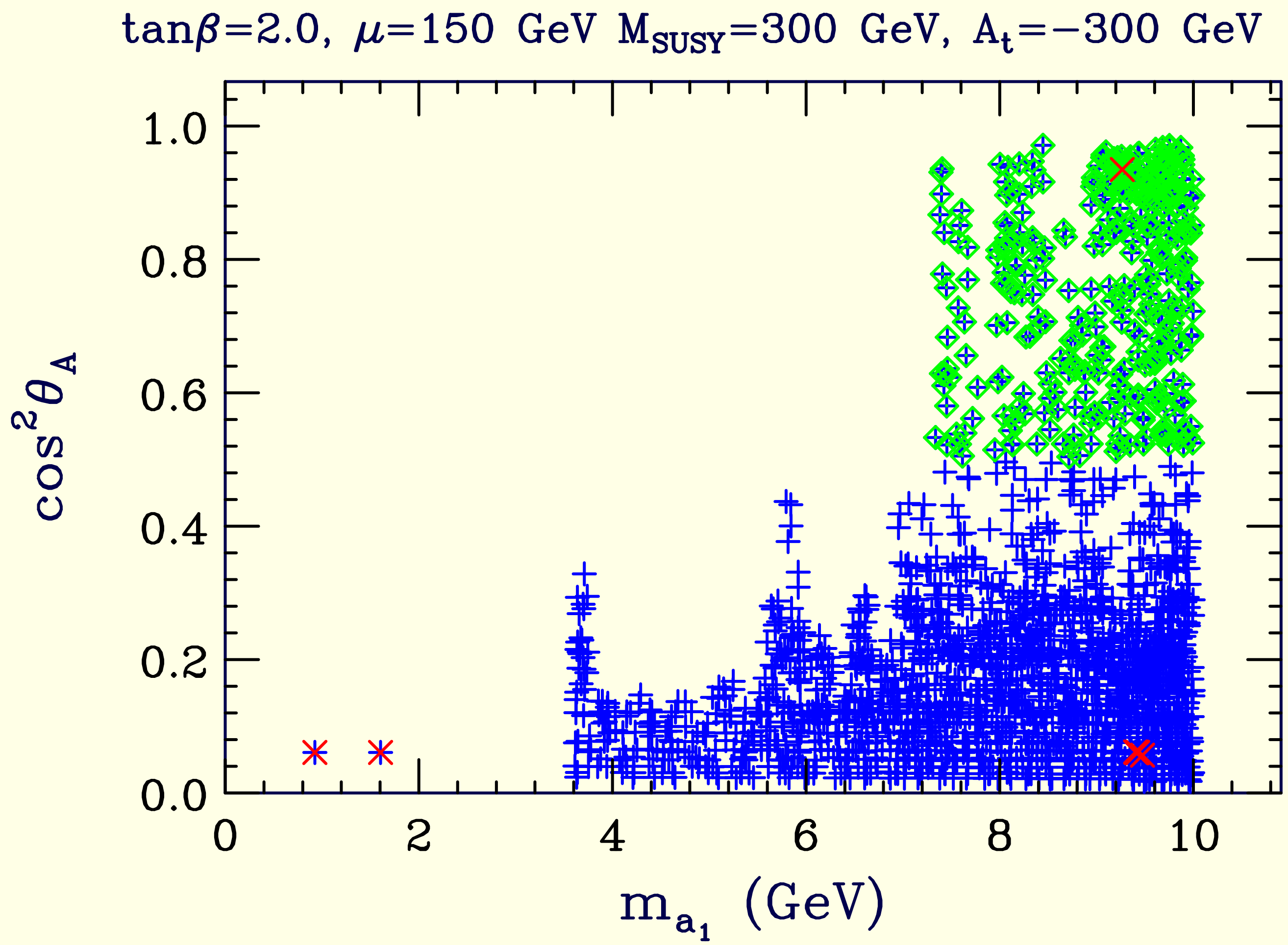


Figure 11: $\cos^2\theta_A$ for allowed scenarios for $\tan\beta = 2$, $m_{\rm SUSY} = 300$ GeV, $A_t = -300$ GeV and $\mu = 150$ GeV.

Green points have $\cos^2\theta_A > 0.5$; blue points have $\cos^2\theta_A < 0.5$. Red crosses have $m_{h_1} < 65$ GeV. Note impact of $|C_{ab\bar b}|$ limits at low m_{a_1};

Tevatron could probe high m_{a_1} with high L.

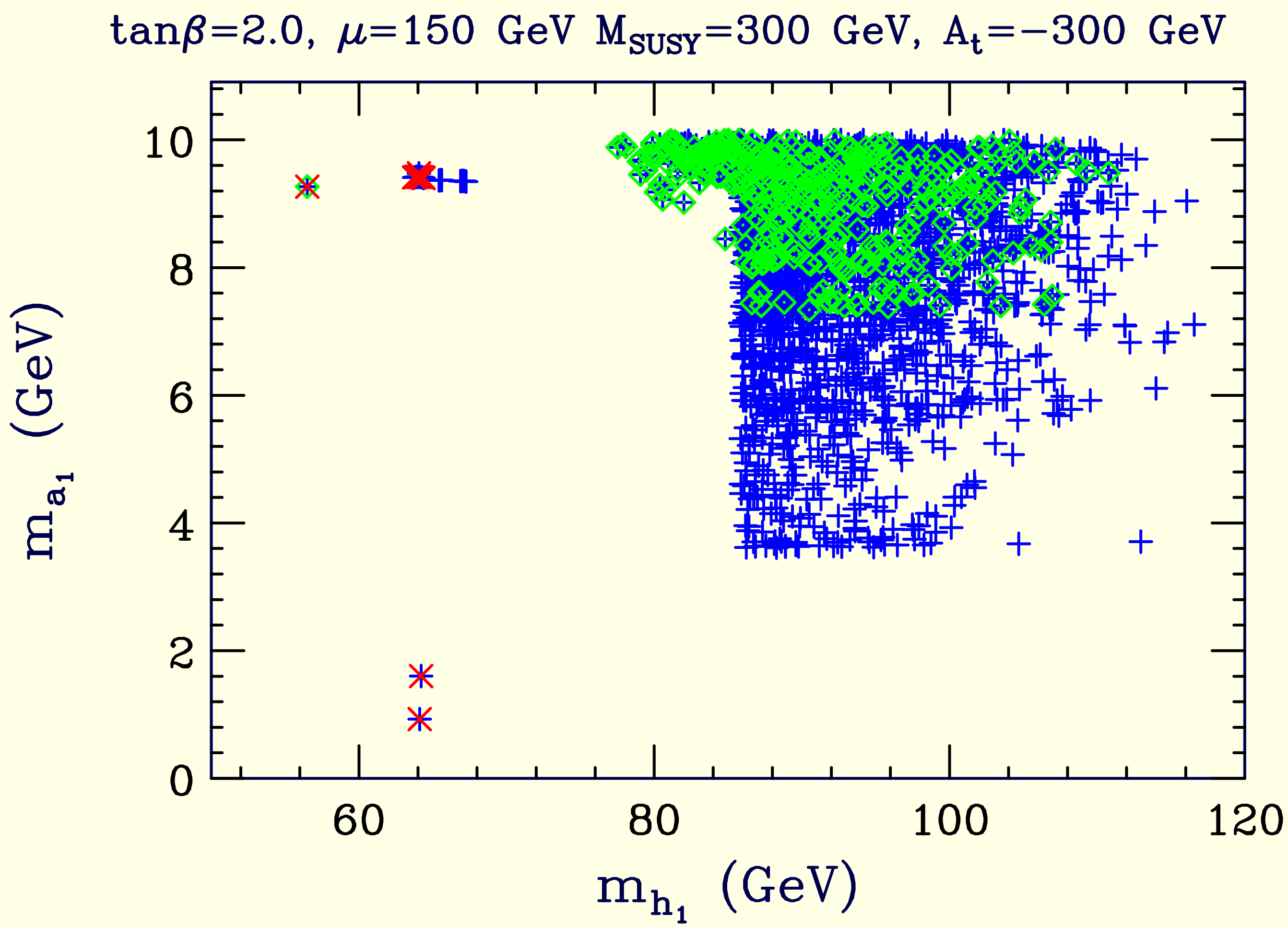


Figure 12: m_{a_1} vs. m_{h_1} for allowed scenarios for $\tan\beta = 2$, $m_{\rm SUSY} = 300$ GeV, $A_t = -300$ GeV and $\mu = 150$ GeV.

Lowest m_{h_1} points have reduced ZZh_1 coupling and large $B(h_1 \to a_1 a_1)$.

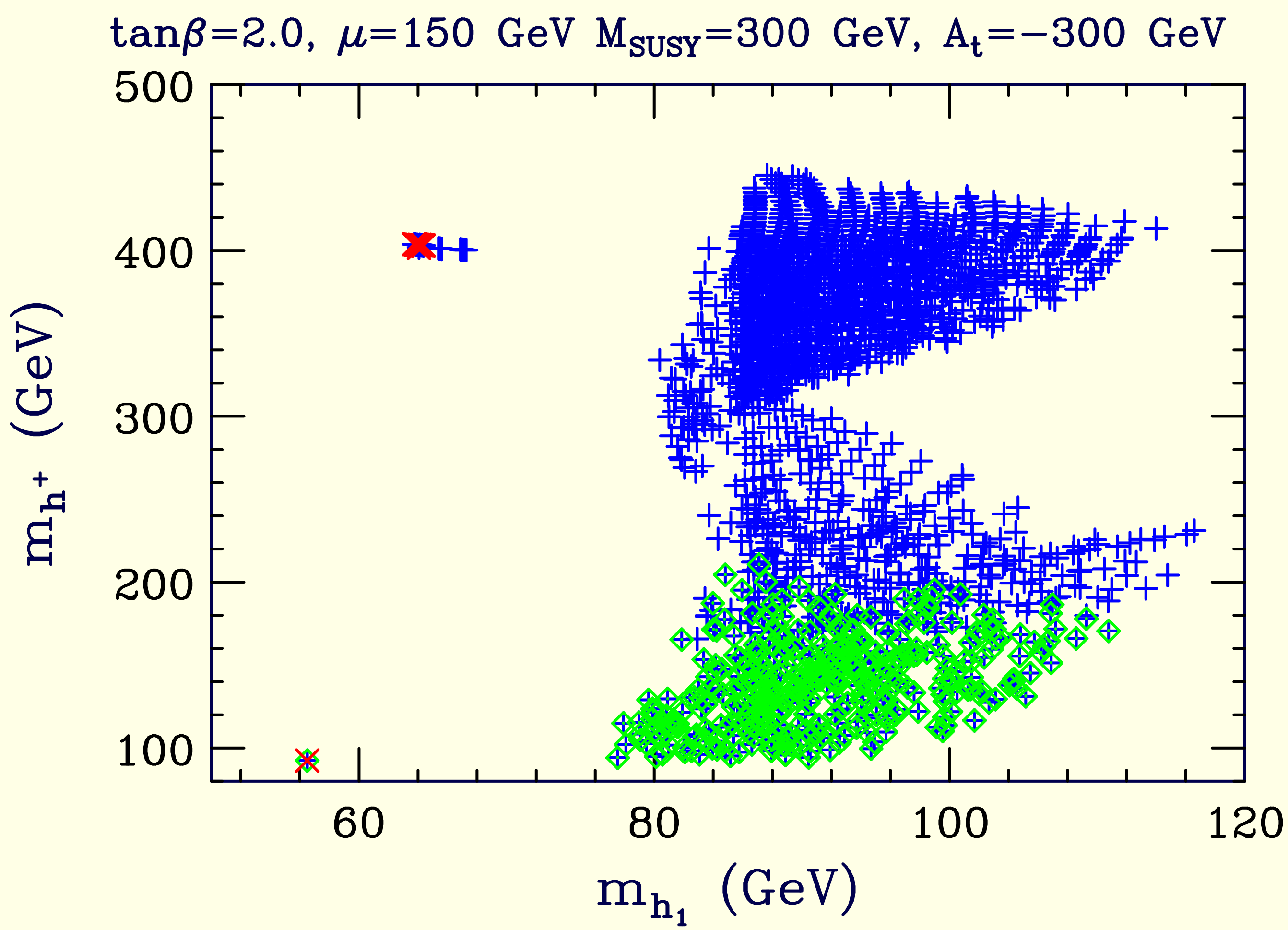


Figure 13: m_{h^+} vs. m_{h_1} for allowed scenarios for $\tan\beta = 2$, $m_{\rm SUSY} = 300$ GeV, $A_t = -300$ GeV and $\mu = 150$ GeV.

Interesting points are those with low m_{h^+}; these have high m_{a_1} and $\cos^2\theta_A > 0.5$ and $m_{h^\pm} \sim m_W$.

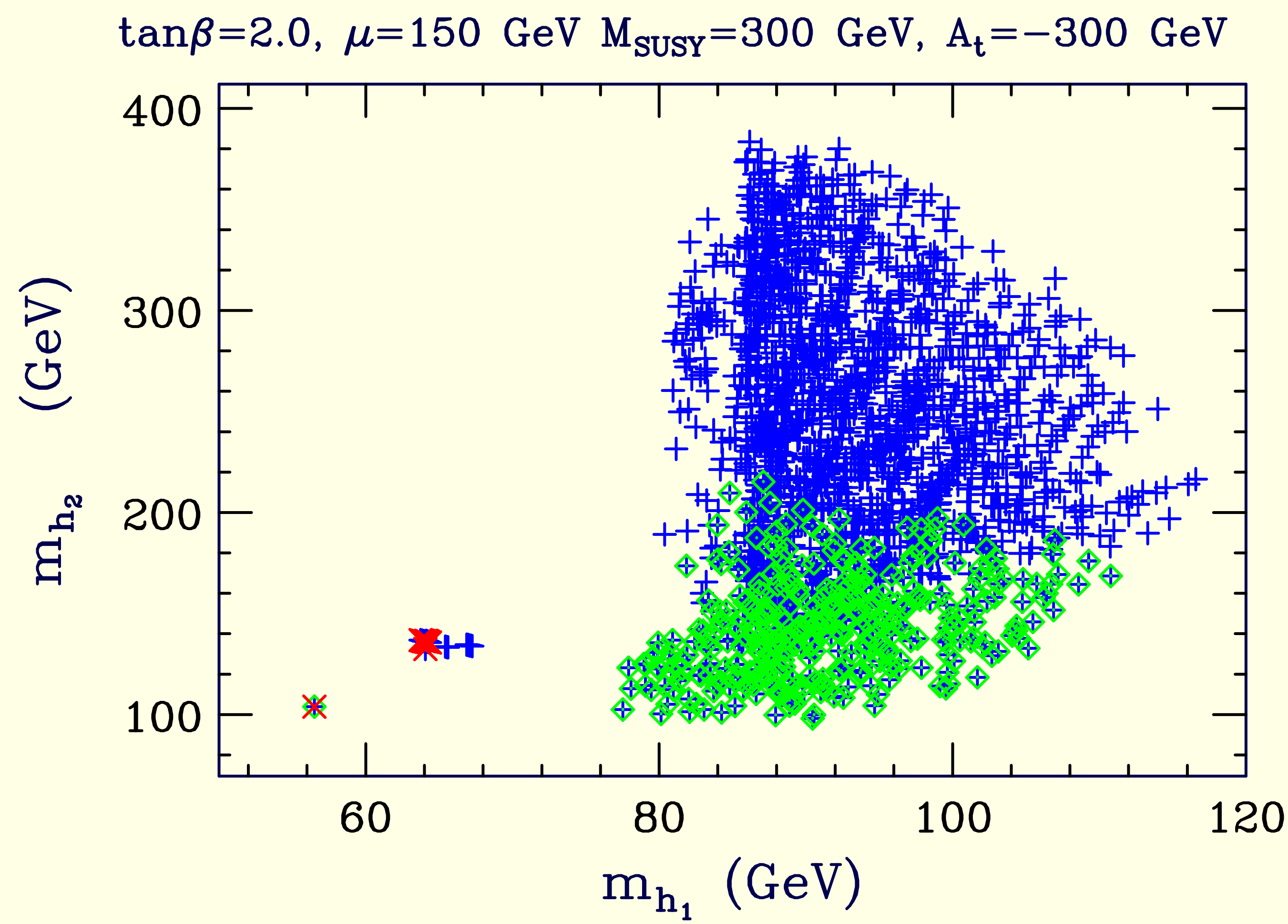


Figure 14: m_{h_2} vs. m_{h_1} for allowed scenarios for $\tan\beta = 2$, $m_{\rm SUSY} = 300~{\rm GeV}$, $A_t = -300~{\rm GeV}$ and $\mu = 150~{\rm GeV}$.

We see that these points also have small m_{h_2}.

LEP facts:

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 $m_{4\tau} < 89~\mathrm{GeV}$ (at best — lower if ZZh_1 coupling is somewhat suppressed).
2. $B(h^+ \to W^+ a_1)$ is often large, and $e^+e^- \to h^+h^- \to W^+W^-a_1a_1$ was not directly searched for.
3. $B(h^+ \to \tau^+\nu)$ is frequently 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/or $e^+e^- \to Zh_2 \to Zb\bar{b}$ would yield a substantial contribution to the LEP $0.1 \times SM$ excess near $m_{b\bar{b}} \sim 98~\mathrm{GeV}$.

Table 2: Selected $\tan\beta = 1.7$ points for which m_{h_1} and corresponding m_{h_2} lie within the LEP excess region and the corresponding $C_V^2(h_1)B(h_1 \to b\bar{b})$ and $C_V^2(h_2)B(h_2 \to b\bar{b})$ values.

m_{h_1}	$C_V^2(h_1)B(h_1 \to b\bar{b})$	m_{h_2}	$C_V^2(h_2)B(h_2 \to b\bar{b})$
93.1	0.0684	96.2	0.1590
90.7	0.0560	96.6	0.1726
90.2	0.1171	97.2	0.1468
88.3	0.0557	97.0	0.1803
87.8	0.0974	97.5	0.1609
90.7	0.0560	96.6	0.1727
92.7	0.1748	97.2	0.1037
90.9	0.0599	97.1	0.1416

The main point is that to observe or constrain the a_1 in these $\cos^2\theta_A > 0.5$ scenarios will most likely require both B-factory Υ results and Tevatron high luminosity data.

High luminosity would also better limit $B(t \to h^+ b)$ which at the moment is allowed up to the 40% level since these decays are included in the way CDF and D0 determine the $t\bar{t}$ cross section for the $h^+ \to W^+ a_1$ decays.

Conclusions

- **A light a with $m_a < 2m_b$ of the "ideal" Higgs scenario with $m_h < 105\ \mathrm{GeV}$ (escaping LEP limits because $B(h \to aa \to 4\tau)$ is large) might be discoverable in the di-muon spectrum at the Tevatron or LHC.**

- **Alternatively, the Tevatron and LHC might be able to place limits on the $C_{ab\bar{b}}$ of a light a that would be difficult to reconcile with a specific model.**

  This appears to be within reach even for the most preferred small-$\cos\theta_A$, $m_a \lesssim 2m_b$ high-$\tan\beta$ NMSSM models.

  Already, the less preferred ($i.e.$ largish G) larger $|\cos\theta_A|$ models in the high-$\tan\beta$ NMSSM scenarios are being ruled out over part of the relevant mass region beyond that accessible in Υ decays.

  Potentially, the hadron colliders could go to higher di-muon masses and they definitely should.

- **Having both Υ decay and hadron collider data appears to be crucial.**

  The former covers the low m_a region (where the di-muon Drell-Yan background overwhelms the hadron collider $a \to \mu^+\mu^-$ signal and muon triggering becomes hard).

  The latter is the only way (and apparently a viable way) to access the higher $m_a \lesssim 2m_B$ and above threshold regions.

- **If we were to see an a with the right properties, this would give enormous impetus to focusing on the $pp \to pph$ and $WW \to h$ with $h \to aa \to 4\tau$ search modes.**

- **For a generic 2HDM-II model, there is only a small $10~\mathrm{GeV} < m_a < 12~\mathrm{GeV}$ window left for which the a might explain Δa_μ and this is possible only if $C_{ab\bar{b}} = \tan\beta$ is large.**

  It would appear that extending the hadron colliders to high enough m_a to rule this out is possible.

- **In the NMSSM:**

  The preferred NMSSM models do not have large $C_{ab\bar{b}} = \cos\theta_A \tan\beta$ coupling.

  Instead, small-G models with high $\tan\beta$ have small $\cos\theta_A$ for which $C_{ab\bar{b}} = \cos\theta_A \tan\beta \lesssim 1$.

  At low $\tan\beta$, $\cos\theta_A$ is larger than 1 for an attractive class of models and Tevatron data might be able to rule out such scenarios for somewhat lower L.