Impact of Minimal Fine-Tuning NMSSM Scenarios on LHC/ILC Complementarity

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LHC/ILC Workshop, Dec. 13, 2005

Outline

1. **Brief Review of NMSSM Low Fine-Tuning Scenarios**

2. **Implications for LHC and ILC**

Brief Review of NMSSM Low-F Scenarios

- **Dermisek and I employ**

$$F = \mathrm{Max}_p F_p \equiv \mathrm{Max}_p \left| \frac{d \log m_Z}{d \log p} \right| , \quad (1)$$

where the parameters p comprise the GUT-scale values of λ, κ, A_λ, A_κ, and the usual soft-SUSY-breaking gaugino, squark, slepton, . . . masses.

- **Dermisek and I have shown that fine-tuning is absent in the NMSSM for precisely those parameter choices for which $h_1 \to a_1 a_1$ decays are present.**

  The plots have $m_{h_1} \geq 114~\mathrm{GeV}$ shown as red $\times$'s and $m_{h_1} < 114~\mathrm{GeV}$ shown as blue $+$'s.

  $F < 10$ **is possible for $m_{h_1} < 114~\mathrm{GeV}$, but $h_1 \to a_1 a_1$ is required.**

  $F \gtrsim 23$ **for $m_{h_1} \geq 114~\mathrm{GeV}$. For such m_{h_1}, $h_1 \to a_1 a_1$ *need not* be dominant or even large, but it *can* be dominant.**

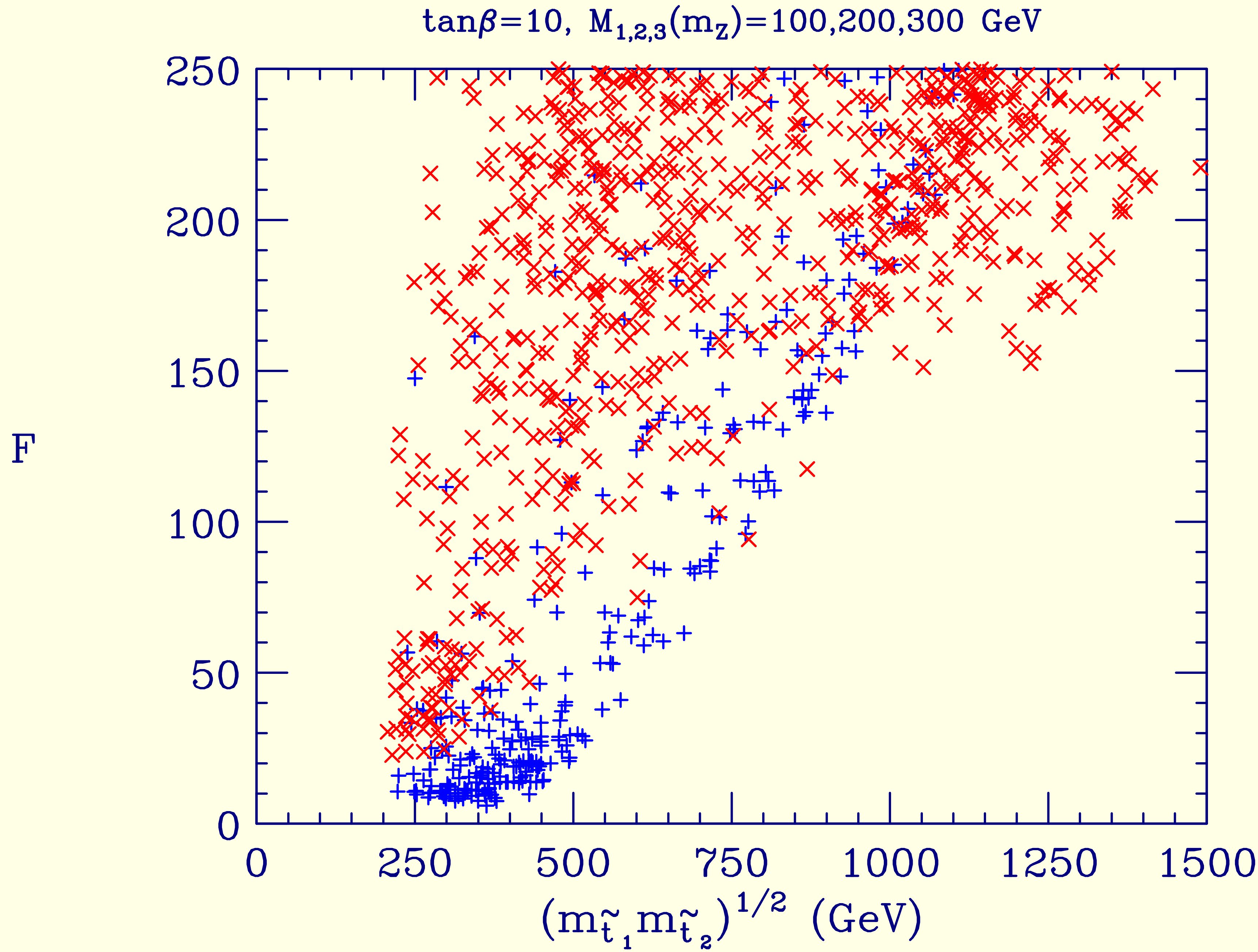


Figure 1: *F* as a function of root mean stop mass after latest *single-channel* **LEP limits.**

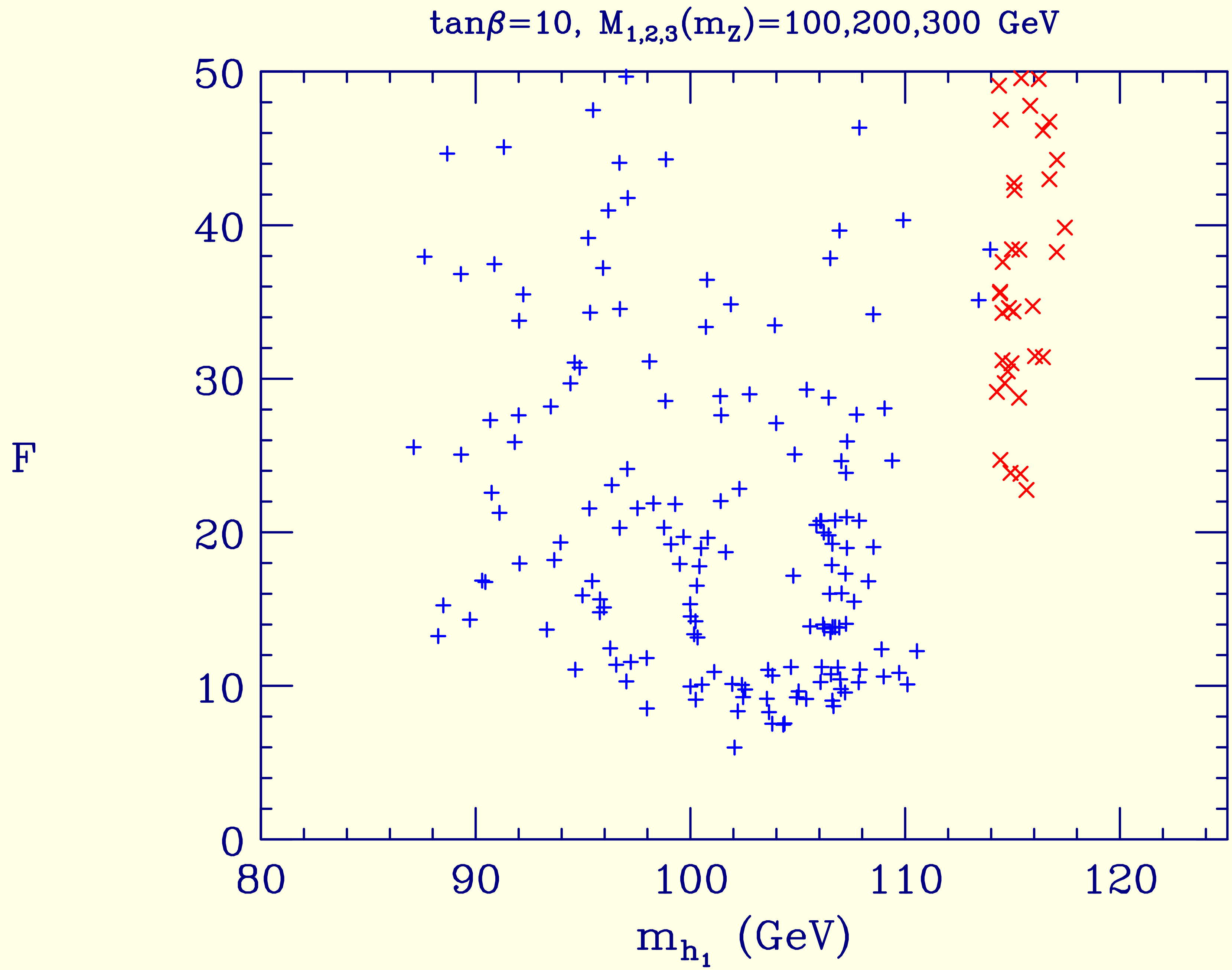


Figure 2: F **as a function of** m_{h_1} **after latest** *single-channel* **LEP limits.**

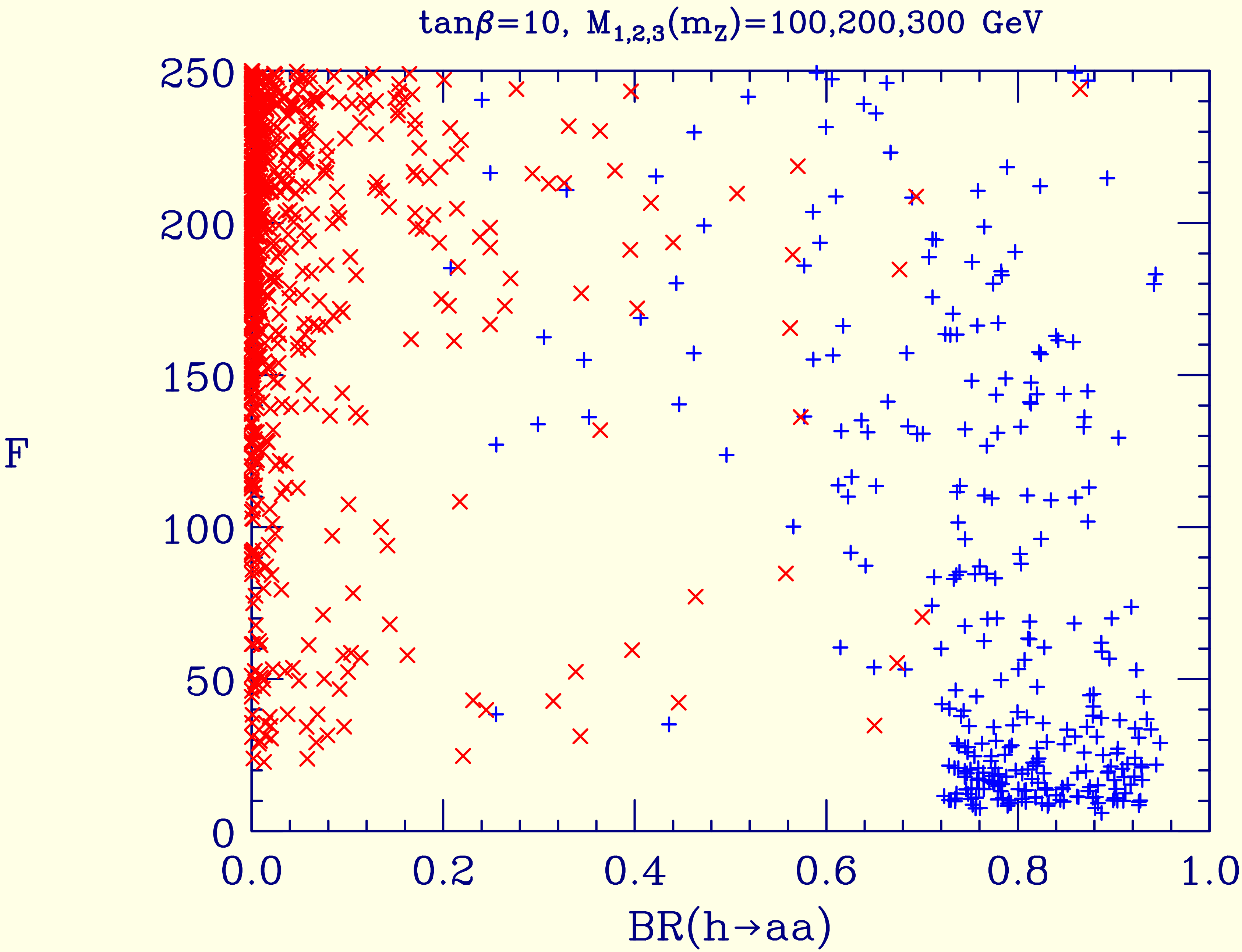


Figure 3: F **as a function of** $B(h_1 \to a_1 a_1)$ **after latest** *single-channel* **LEP limits.**

- When $h_1 \to a_1 a_1$ is dominant, LHC Higgs discovery will have to employ this mode. There are then two classes of points: those with $m_{a_1} > 2m_b$ and those with $m_{a_1} < 2m_b$. LHC/ILC complementarity issues depend strongly on which is the case.

- Putting the $F < 10$ scenarios with $m_{a_1} > 2m_b$ through the full LHWG analysis, one finds that all are excluded at somewhat more than the 99% CL.

  In fact, all the $m_{a_1} > 2m_b$ scenarios with $m_{h_1} \lesssim 108 \div 110~\mathrm{GeV}$ are ruled out at a similar level. What is happening is that you can change the $h_1 \to b\bar{b}$ direct decay branching ratio and you can change the $h_1 \to a_1 a_1 \to 4b$ branching ratio, but roughly speaking $B(h_1 \to b's) \gtrsim 0.85$ (a kind of sum rule). So, if the ZZh_1 coupling is full strength (as is the case in all the scenarios with any kind of reasonable F) there is no escape except high enough m_{h_1}.

- The only way to achieve really low F, which comes with low m_{h_1}, and remain consistent with LEP is to have $m_{a_1} < 2m_b$. In fact, there are more low-F scenarios of this type than there are ones with $m_{a_1} > 2m_b$!

  Let us examine the $F < 10$, $m_{a_1} < 2m_b$ scenarios. The relevant limit from LEP is now only that from the $Z2b$ channel. (It turns out that LEP has never placed limits on the $Z4\tau$ channel for h masses larger than about $87~\mathrm{GeV}$ —- I am told this is unlikely to ever be revisited, but I am pushing.)

- **Note:** Such a light to very light a_1 is not excluded by Υ, ... precision decay measurements since the a_1 turns out to be very singlet-like for all the low-F scenarios.

- To really see how well the $F < 10$, $m_{a_1} < 2m_b$ points describe the LEP excesses we have to run them through the full LHWG code.

  In Table 1, we give the precise masses and branching ratios of the h_1 and a_1 for all the $F < 10$ points.

  We also give the number of standard deviations, $n_{\rm obs}$ ($n_{\rm exp}$) by which the observed rate (expected rate obtained for the predicted signal+background) exceeds the predicted background. The numbers are obtained after full processing of all Zh final states using the preliminary LHWG analysis code (thanks to P. Bechtle). They are derived from $(1 - CL_b)_{\rm observed}$ and $(1 - CL_b)_{\rm expected}$ using the usual tables: e.g. $(1 - CL_b) = 0.32$, 0.045, 0.0027 correspond to 1σ, 2σ, 3σ excesses, respectively.

The quantity $s95$ is the factor by which the signal predicted in a given case would have to be multiplied in order to exceed the 95% CL. All these quantities are obtained by processing each scenario through the full preliminary LHWG confidence level/likelihood analysis.

m_{h_1}/m_{a_1} (GeV)	Branching Ratios			$n_{\rm obs}/n_{\rm exp}$ units of 1σ	$s95$	N_{SD}^{LHC}
	$h_1 \to b\overline{b}$	$h_1 \to a_1 a_1$	$a_1 \to \tau\overline{\tau}$			
98.0/2.6	0.062	0.926	0.000	2.25/1.72	2.79	1.2
100.0/9.3	0.075	0.910	0.852	1.98/1.88	2.40	1.5
100.2/3.1	0.141	0.832	0.000	2.26/2.78	1.31	2.5
102.0/7.3	0.095	0.887	0.923	1.44/2.08	1.58	1.6
102.2/3.6	0.177	0.789	0.814	1.80/3.12	1.03	3.3
102.4/9.0	0.173	0.793	0.875	1.79/3.03	1.07	3.6
102.5/5.4	0.128	0.848	0.938	1.64/2.46	1.24	2.4
105.0/5.3	0.062	0.926	0.938	1.11/1.52	2.74	1.2

Table 1: Some properties of the h_1 and a_1 for the eight allowed points with $F < 10$ and $m_{a_1} < 2m_b$ from our $\tan\beta = 10$, $M_{1,2,3}(m_Z) = 100, 200, 300~\mathrm{GeV}$ NMSSM scan. N_{SD}^{LHC} is the statistical significance of the best "standard" LHC Higgs detection channel for integrated luminosity of $L = 300~\mathrm{fb}^{-1}$.

Comments

- If $n_{\rm exp}$ is larger than $n_{\rm obs}$ then the excess predicted by the signal plus background Monte Carlo is larger than the excess actually observed and vice versa.
- The points with $m_{h_1} \lesssim 100~{\rm GeV}$ have the largest $n_{\rm obs}$.
- Point 2 gives the best consistency between $n_{\rm obs}$ and $n_{\rm exp}$, with a predicted excess only slightly smaller than that observed.
- Points 1 and 3 also show substantial consistency.
- For the 4th and 7th points, the predicted excess is only modestly larger (roughly within 1σ) compared to that observed.
- The 5th and 6th points are very close to the 95% CL borderline and have a predicted signal that is significantly larger than the excess observed.
- LEP is not very sensitive to point 8.

Thus, a significant fraction of the $F < 10$ points are very consistent with the observed event excess.

Collider Implications

- An important question is the extent to which the type of $h \to aa$ Higgs scenario (whether NMSSM or other) described here can be explored at the Tevatron, the LHC and a future e^+e^- linear collider.

  At the first level of thought, the $h_1 \to a_1 a_1$ decay mode renders inadequate the usual Higgs search modes that might allow h_1 discovery at the LHC.

  Since the other NMSSM Higgs bosons are rather heavy and have couplings to b quarks that are not greatly enhanced, they too cannot be detected at the LHC.

  The last column of Table 1 shows the statistical significance of the most significant signal for *any* of the NMSSM Higgs bosons in the "standard" SM/MSSM search channels for the eight $F < 10$ NMSSM parameter choices. We have a problem.

  For the h_1 and a_1, the most important detection channels are $h_1 \to \gamma\gamma$, $Wh_1 + t\bar{t}h_1 \to \gamma\gamma\ell^\pm X$, $t\bar{t}h_1/a_1 \to t\bar{t}b\bar{b}$, $b\bar{b}h_1/a_1 \to b\bar{b}\tau^+\tau^-$ and $WW \to h_1 \to \tau^+\tau^-$.

Even after $L = 300~\mathrm{fb}^{-1}$ of accumulated luminosity, the typical maximal signal strength is at best 3.5σ. For the eight points of Table 1, this largest signal derives from the $Wh_1 + t\bar{t}h_1 \to \gamma\gamma\ell^\pm X$ channel.

There is a clear need to develop detection modes sensitive to the $h_1 \to a_1a_1 \to \tau^+\tau^-\tau^+\tau^-$ and (unfortunately) $4j$ decay channels.

I will focus on 4τ in my discussion of possibilities below, but keep in mind the $4j$ case.

- I have absolutely no answers, but what I want to do here is to simply make a list of what needs to be done.

  There is a lot of work ahead for our experimental colleagues.

  I hope we can have discussion as I go through the various modes.

Perhaps it is useful to remind ourselves of the standard LHC cross sections.

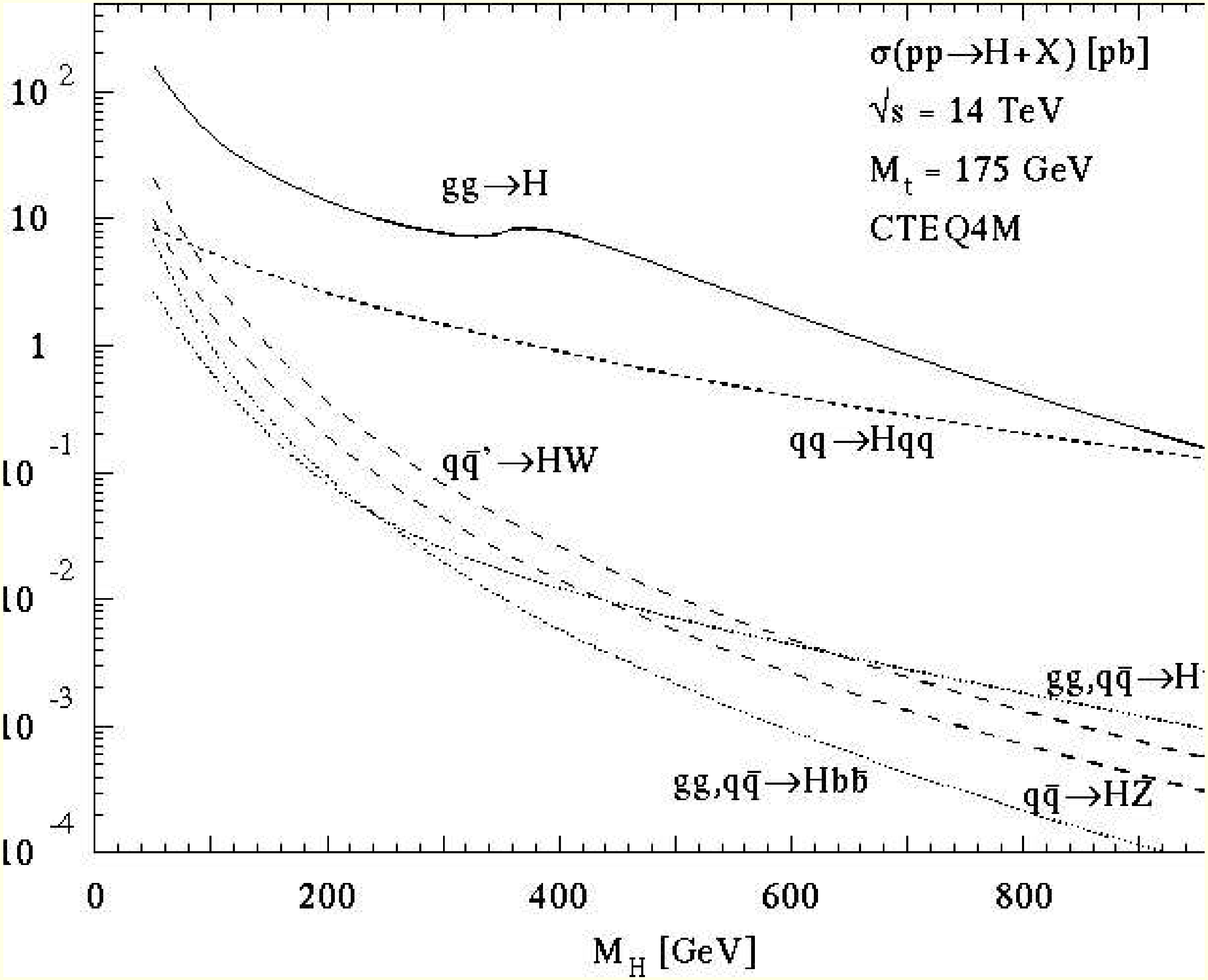


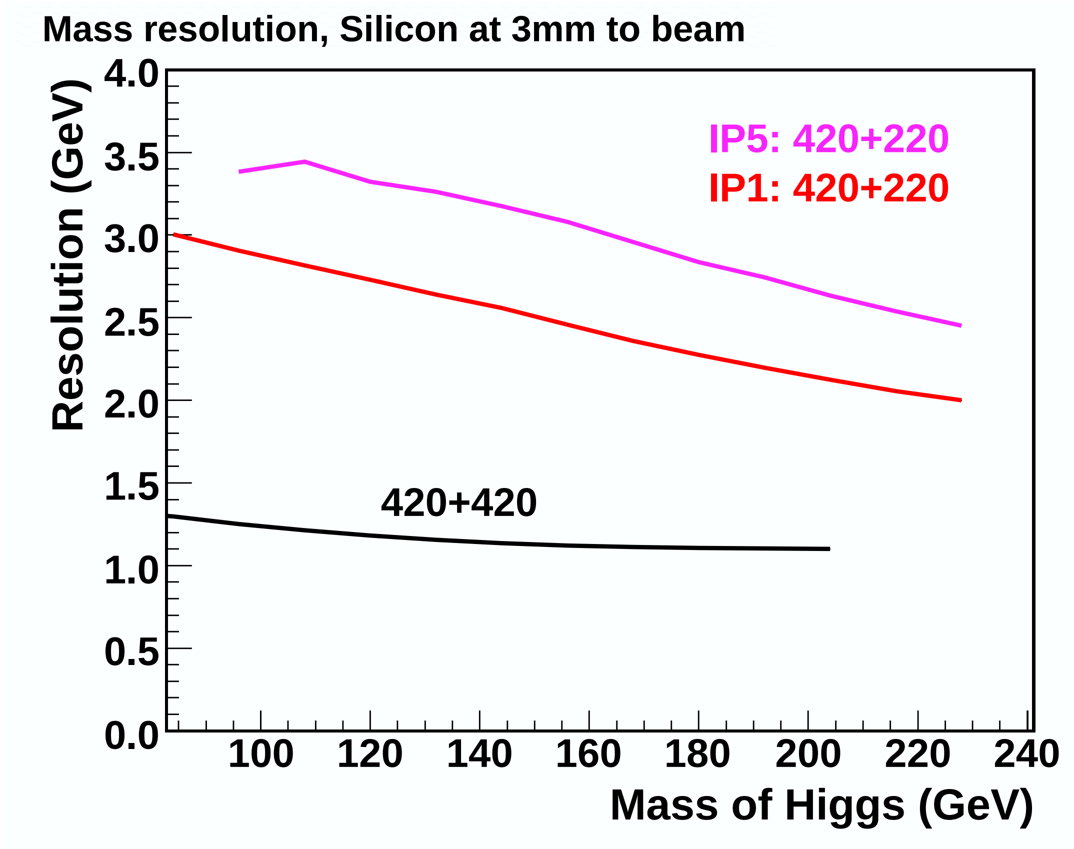
Figure 4: The standard Higgs production cross sections at the LHC.

Hadron Colliders

1. One detection mode that can be considered is $WW \to h_1 \to a_1 a_1 \to 4\tau$.
   We know that the cross section is not bad.
   The events can be triggered by the forward jets, which triggering also cleans up the background.
   The 4τ mode might in the end actually be fairly background free?
   One of course has to recognize overlapping τ's, which might yield lower efficiency for finding the events of interest.
   Assuming the τ's can be found, there would be some ability to reconstruct m_{h_1} using the fact that the two τ's from one light a_1 are quite collinear and so you could do the usual collinear mass reconstruction game of treating the two τ pairs as two objects with collinear visible momentum and missing momentum.
2. Another mode is $t\bar{t}h_1 \to t\bar{t}a_1 a_1 \to t\bar{t}\tau^+\tau^-\tau^+\tau^-$.
   Many of the above remarks again apply.
   Of course, the cross section is smaller.
3. Is it possible that this 4τ final state is actually easier for the above modes than the $b\bar{b}b\bar{b}$ and $b\bar{b}\tau^+\tau^-$ final states that must be considered if $m_{a_1} > 2m_b$?

4. Third, recall that the $\widetilde{\chi}_2^0 \to h_1 \widetilde{\chi}_1^0$ channel provides a signal in the MSSM when $h_1 \to b\bar{b}$ decays are dominant.
   It has not been studied for $h_1 \to a_1 a_1 \to 4\tau$ decays.
   If a light $\widetilde{\chi}_1^0$ provides the dark matter of the universe (as possible because of the $\widetilde{\chi}_1^0 \widetilde{\chi}_1^0 \to a_1 \to X$ annihilation channels for a light a_1, see JFG, McElrath, Hooper and Belanger et al, and references therein), the $m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0}$ mass difference might be large enough to allow such decays.

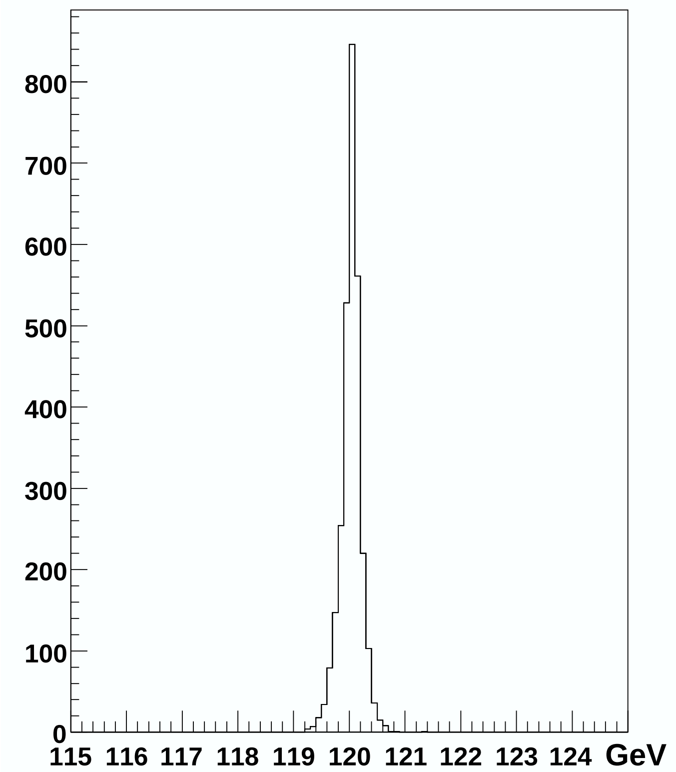
5. Last, but perhaps not least, diffractive production $pp \to pph_1 \to ppX$.
   I think we all must have a serious look at this detection mode.
   - A study (JFG, Khoze, de Roeck, Ryskin, ...) is underway to see if this discovery mode works for the $h_1 \to a_1 a_1 \to 4\tau$ decay mode.
   - The big advantage of this mode is that the mass M_X can be reconstructed with roughly a $1-2~\mathrm{GeV}$ resolution.
     $\Rightarrow$ can potentially reveal a Higgs peak, independent of the decay of the Higgs.
     In the following plot, it is mainly the $420-420$ resolution that matters.
     All my plots are taken from P. Bussey's talk at the Manchester Workshop earlier this week.
     The main issue may be whether events can be triggered.



Calculated for silicon 3mm from beam; results similar (given acceptance) for other distances.

Figure 5: Higgs mass resolution.

Resulting mass distribution from 120 GeV Higgs Exhume file:



which is encouraging.

Figure 6: Higgs mass peak.

- **The cross section is adequate, but not wonderful if you believe the Khoze-Ryskin-... cross sections.**
  At the recent Manchester conference I became convinced that their cross sections are probably the most reliable.
  The following plot shows their result. The amount of rapidity acceptance is a bit uncertain, but probably can use $\Delta y \sim 1$ (perhaps a bit more) $\Rightarrow \sigma \sim 1~\mathrm{fb}$.
  Note: In the NMSSM scenarios, the production rate is essentially equal to the SM rate since this rate relies on the nearly SM-like ggh_1 coupling strength.
- **Of course, you must realize that this diffractive business can only be done (they say) at low luminosity so we can imagine accumulating at most $30~\mathrm{fb}^{-1}$.**
  $\Rightarrow$ 30 events before efficiencies and such, which are usually a significant issue. In particular, as discussed shortly we will have to worry about acceptance and triggering.
  There is probably a factor of 2 or 3 uncertainty that should be attached to these predictions (in either direction). $\Rightarrow$ we could hope for something larger.
  Also, other groups predict larger cross sections, but on the basis of what I regard as questionable models.

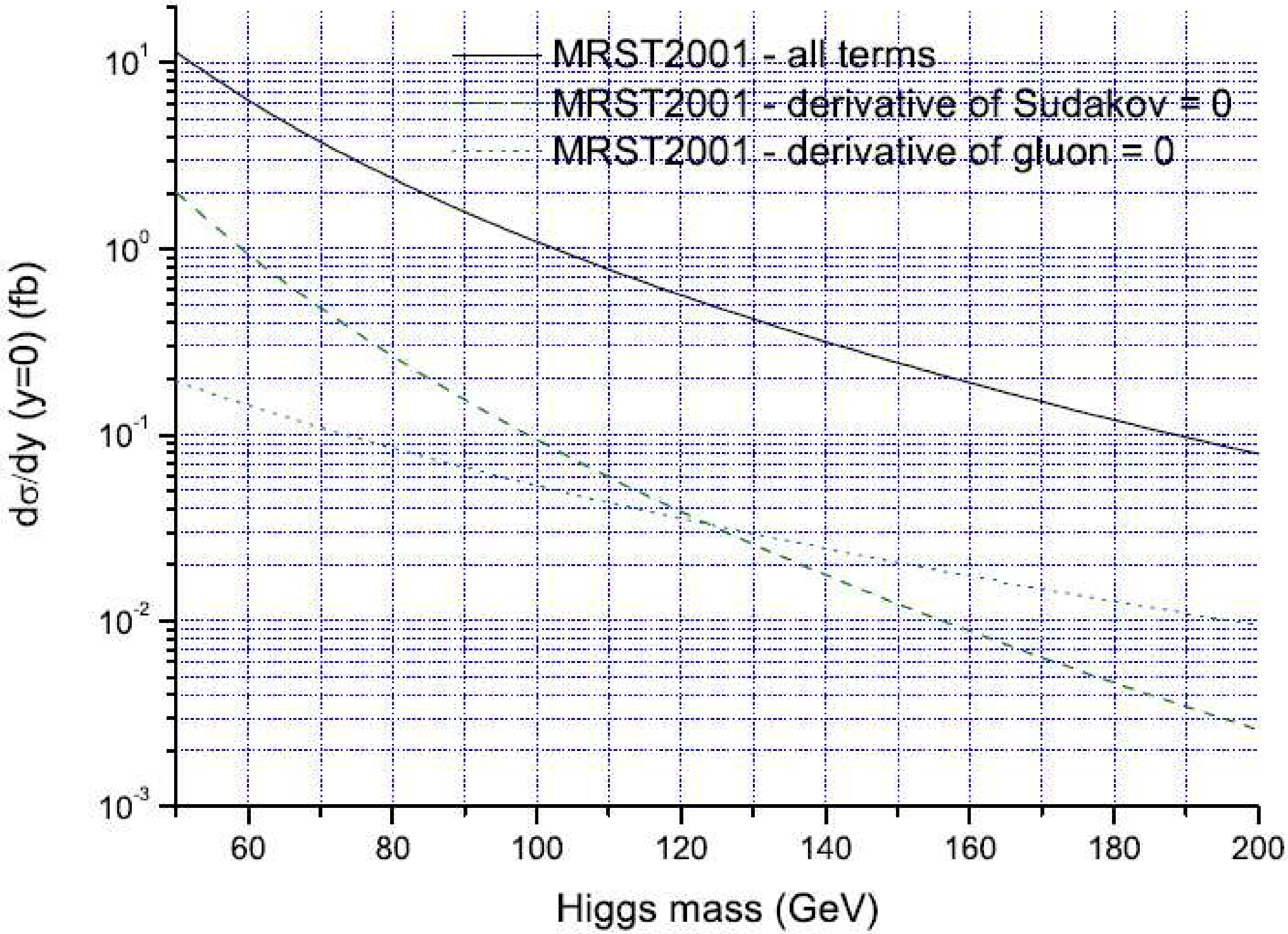
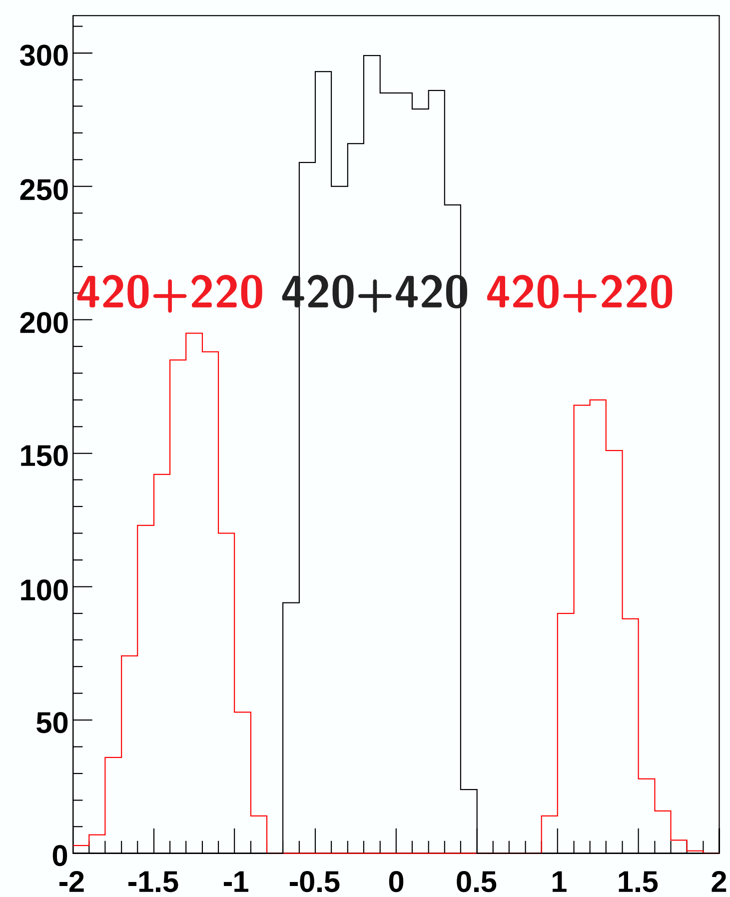


Figure 7: The standard Higgs diffractive production cross section at the LHC at $y = 0$. Multiply by $\Delta y = ?$.

RAPIDITY OF CENTRAL HIGGS



Rapidity of central Higgs (IP1) for 120 GeV Higgs (silicon at 3 mm from beam)

Histograms for events with both protons accepted in Roman Pots.

Can we trigger on jet pairs whose angles correspond to these ranges?

Figure 8: Rapidity acceptances for different combinations of forward detectors. As we shall see, can probably only use the $420-420$ part.

- We should note that the recent $\gamma\gamma$ diffractive detection (Albrow, Goulianos, ...) appears to roughly confirm Khoze, Ryskin, ... techniques.
- Despite the small event rate, the very narrow mass resolution and the hopefully background-free nature of a 4τ final state after already requiring the forward protons might imply that we need only a few events in a single M_X bin to believe that something is there.
- **Acceptance**

  Recall that currently (i.e. without a major expenditure on extra time delays in the level 1 pipeline), one cannot use the 420 m distant proton detectors to trigger and still be able to have other information for the event retained.

  However, the 220 m proton detectors just fall within the level 1 trigger time delay and could be used.

  The acceptance as a function of m_h is different for the $420-420$ combination vs. the $220-420$ and $220-220$ combinations.

  Basically, there is too little acceptance for a light Higgs to use any but the $420-420$.

  And, for $m_h \sim 100~\mathrm{GeV}$ it is critical that one be able to put the detectors very close to the beam (and, recall, they are sort of inside the beam pipe).

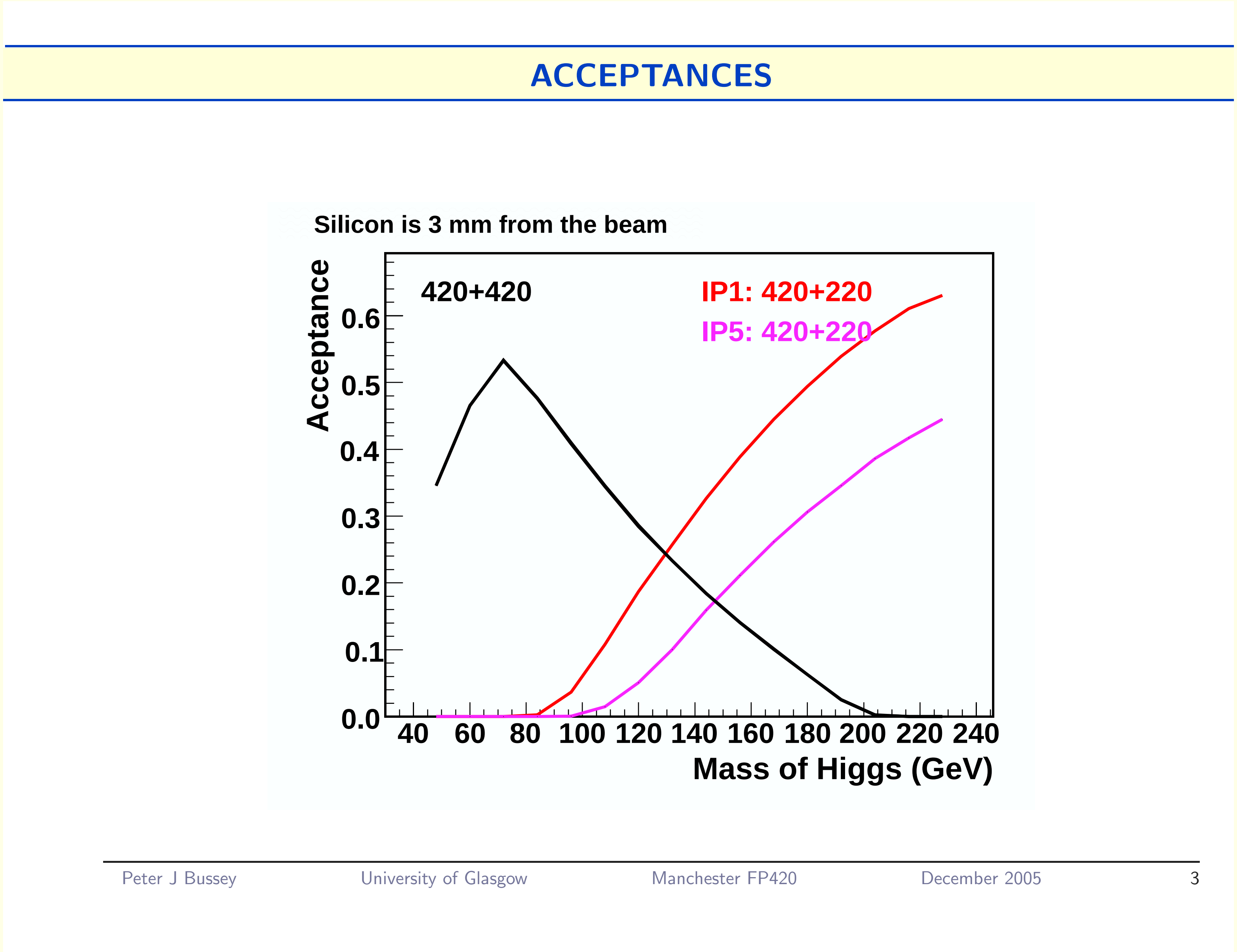


Figure 9: Double diffractive acceptances. Note this is for proton detectors as close to beam as possible — claim is that radiation not too terrible.

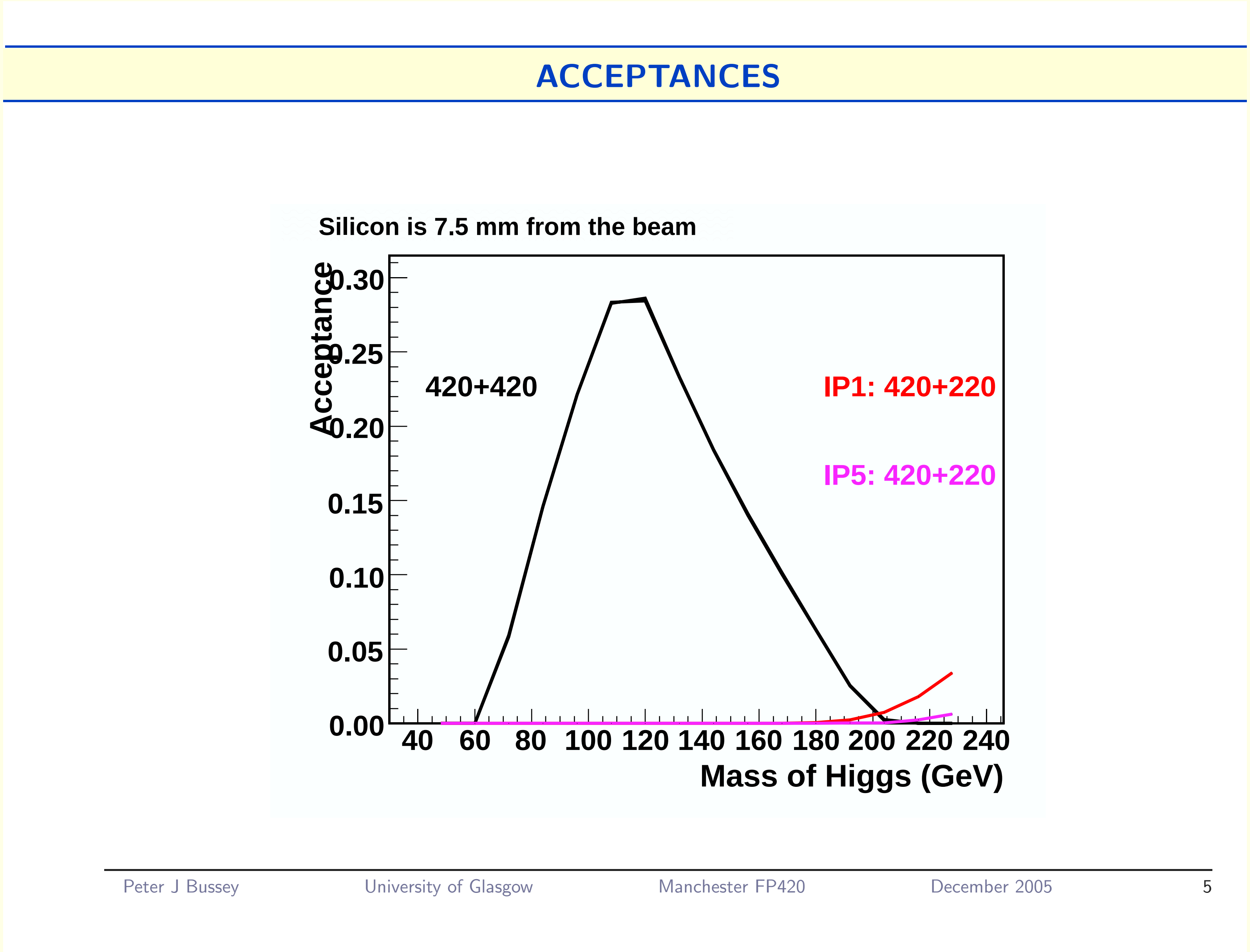


Figure 10: Double diffractive acceptances. Note decrease for further out detectors.

ACCEPTANCES

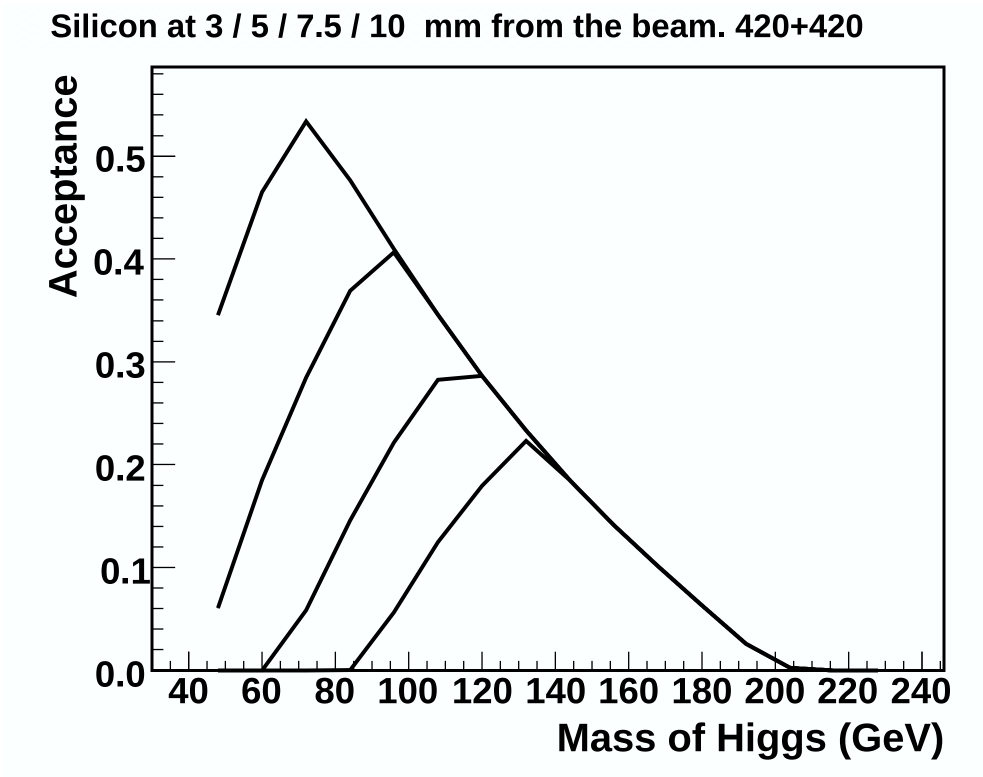


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Figure 11: Double diffractive acceptances—overall view.

– **Triggering**

For the $420-420$, triggering would have to employ the decay products of the centrally produced Higgs.

– Thus, one has to trigger on the decay products of the τ's.

A di-muon trigger might not have too bad an efficiency.

First, although the μ decay products of the τ's are soft, triggering is possible down to μ transverse momentum of just $3~\mathrm{GeV}$.

Second, the branching ratio for getting two μ's from four τ's is also not bad.

However, one must keep in mind that the event will have two pairs of overlapping τ's. But, μ tracking is so good that this is probably not an issue.

- **Any hope at the Tevatron?**

At the Tevatron it is possible that Zh_1 and Wh_1 production, with $h_1 \to a_1a_1 \to 4\tau$, will provide the most favorable channels.

If backgrounds are small, one must simply accumulate enough events.

However, efficiencies for triggering on and isolating the 4τ final state will not be large.

Conway, is pessimistic.

- Perhaps one could also consider $gg \to h_1 \to a_1 a_1 \to 4\tau$ which would have substantially larger rate and maybe still not much background.

  Studies are needed.

- **Scenarios**

  If supersymmetry is detected at the Tevatron, but no Higgs is seen, and if LHC discovery of the h_1 remains uncertain, the question will arise of whether Tevatron running should be extended so as to allow eventual discovery of $h_1 \to 4\tau$.

  However, rates imply that the h_1 signal could only be seen if Tevatron running is extended until $L > 20~\mathrm{fb}^{-1}$ (maybe more) has been accumulated.

  And, there is the risk that $m_{a_1} < 2m_\tau$, in which case Tevatron backgrounds in the above modes would be impossibly large.

- **Failsafe LHC Fall-back**

  If the LHC is unable to see any of the NMSSM Higgs bosons, it *would* observe numerous supersymmetry signals and *would* confirm that $WW \rightarrow WW$ scattering is perturbative, implying that something like a light Higgs boson must be present.

  Maybe one could then go back to low luminosity running and accumulate more in the diffractive mode.

Lepton Colliders

- **Of course, discovery of the h_1 will be straightforward at an e^+e^- linear collider via the inclusive $Zh \rightarrow \ell^+\ell^- X$ reconstructed M_X approach (which allows Higgs discovery independent of the Higgs decay mode).**

  I show a few standard plots.

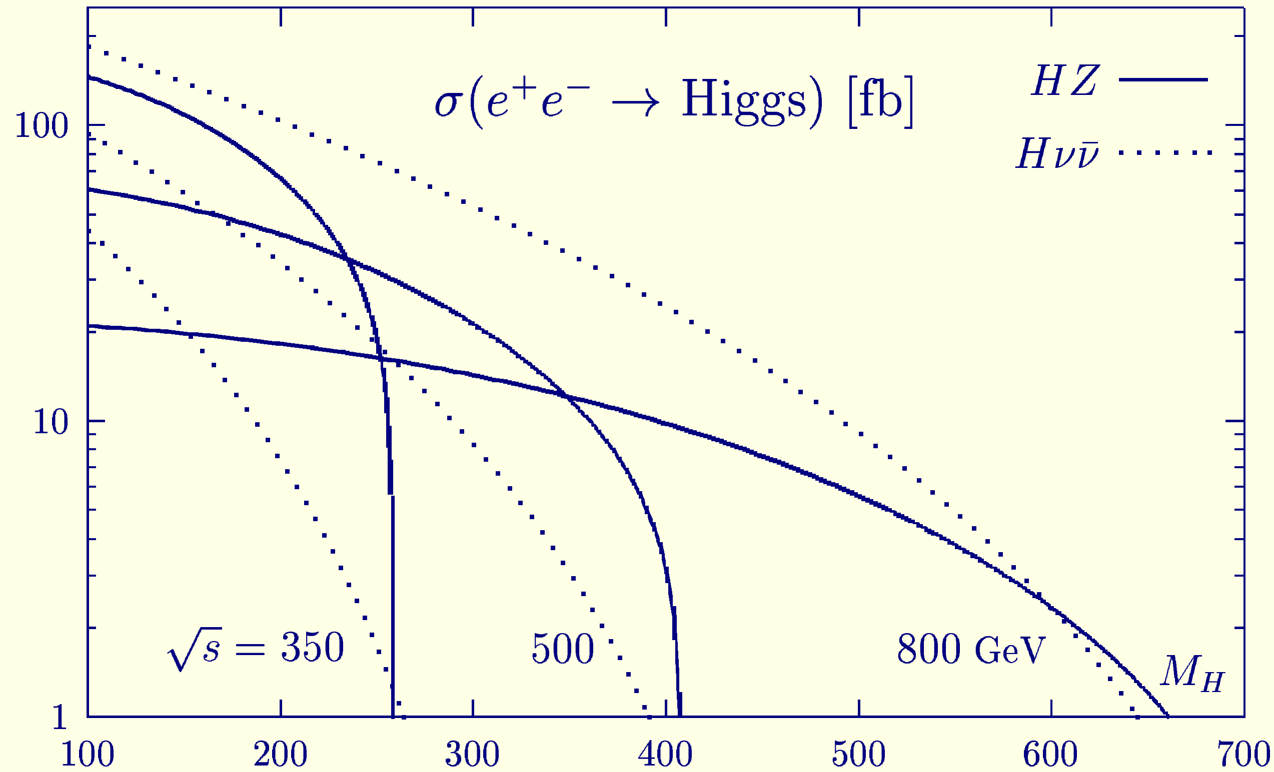

Figure 12: Cross sections at the ILC.

With integrated luminosity of $L = 300\ \mathrm{fb}^{-1}$ say , as you all know we get a large number of Higgs production events before efficiencies. For example at $\sqrt{s} = 350$ GeV and $m_{h_1} = 100$ GeV we produce more than 3×10^4 Higgs bosons in the Zh_1 mode.

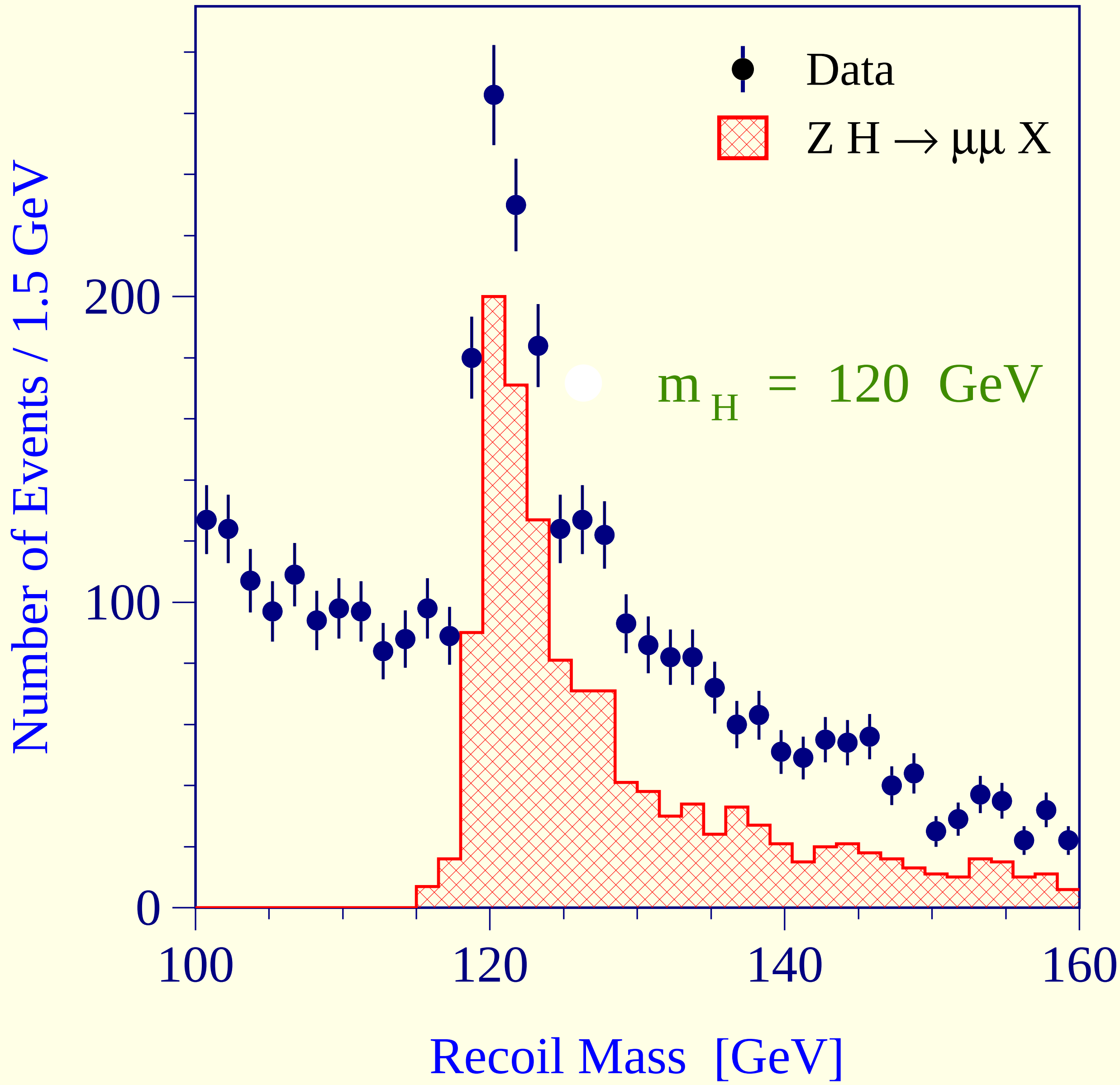

Figure 13: Decay-mode-independent Higgs M_X peak in the $Zh \to \mu^+\mu^- X$ mode for $L = 500~\mathrm{fb}^{-1}$ at $\sqrt{s} = 350~\mathrm{GeV}$, taking $m_h = 120~\mathrm{GeV}$..

There are lots of events in just the $\mu^+\mu^-$ channel (which however you may want to restrict to since it has the best mass resolution).

- Although the $h \to b\bar{b}$ and $h \to \tau^+\tau^-$ rates are 1/10 of the normal, the number of Higgs produced will be such that you can certainly see $Zh \to Zb\bar{b}$ and $Zh \to Z\tau^+\tau^-$ in a variety of Z decay modes.

  This is quite important, as it will allow you to subtract these modes off and get a determination of $B(h_1 \to a_1 a_1)$, which is probably the only way to directly measure the crucial λ coupling.

  Of course, the errors for branching ratios to all the usual channels will be statistically increased by a factor of roughly $\sqrt{10}$ due to decreased branching ratios of h_1 to $b\bar{b}$, $\tau^+\tau^-$, . . . (i.e. any usual channel).

  I have not thought carefully, but I guess the g_{ZZh} measurement would not be much affected since (if I am remembering correctly) that was without using a given final state (otherwise it can't be better than the square root of the error for hbb).

  The standard SM table appears below.

Higgs coupling	δBR/BR	$\delta g/g$
hWW	5.1%	1.2%
hZZ	—	1.2%
htt	—	2.2%
hbb	2.4%	2.1%
hcc	8.3%	3.1%
$h\tau\tau$	5.0%	3.2%
$h\mu\mu$	$\sim 30\%$	$\sim 15\%$
hgg	5.5%	
$h\gamma\gamma$	16%	
hhh	—	$\sim 20\%$

Table 2: Expected fractional uncertainties for measurements of Higgs branching ratios [BR($h \to X\overline{X}$)] and couplings [g_{hXX}], for various choices of final state $X\overline{X}$, assuming $m_h = 120$ GeV at the LC. In all but four cases, the results shown are based on 500 fb^{-1} of data at $\sqrt{s} = 500$ GeV. Results for $h\gamma\gamma$, $ht\bar{t}$, $h\mu\mu$ and hhh are based on 1 ab^{-1} of data at $\sqrt{s} = 500$ GeV (for $\gamma\gamma$ and hh) and $\sqrt{s} = 800$ GeV (for tt and $\mu\mu$), respectively.

- **Presumably direct detection in the $Zh \to Za_1a_1 \to Z4\tau$ mode will also be possible although I am unaware of any actual studies.**

  This would give a direct measurement of $B(h_1 \to a_1a_1 \to \tau^+\tau^-\tau^+\tau^-)$. Error?

- **Coupled with the indirect measurement of $B(h_1 \to a_1a_1)$ from subtracting the direct $b\bar{b}$ and $\tau^+\tau^-$ modes would give a measurement of $B(a_1 \to \tau^+\tau^-)$.**

  This would allow a first unfolding of information about the a_1 itself.

  Of course, the above assumes we have accounted for all modes.

- **Maybe, given the large event rate, one could even get a handle on modes such as $h_1 \to a_1a_1 \to \tau^+\tau^-jj$ ($j = c, g$), thereby getting still more cross checks.**

  This latter will not have high accuracy if $B(a_1 \to \tau^+\tau^-) > 0.9$ as is the model prediction. But, certainly it should be checked against the $B(h_1 \to \tau^+\tau^-)$ value obtained, as outlined above, if at all possible.

- **At a $\gamma\gamma$ collider, the $\gamma\gamma \to h \to 4\tau$ signal will be easily seen (Gunion, Szleper).**

This could help provide still more information about the h.

- In contrast, since (as already noted) the a_1 in these low-F NMSSM scenarios is fairly singlet in nature, its *direct* (i.e. not in h_1 decays) detection will be very challenging even at the ILC.

  We plan to look at such reactions as $e^+e^- \to Za_1a_1$, the cross section for which would be large if the a_1 had no singlet part, but is suppressed by $\cos^2\theta_{a_1}$, where $\cos\theta_{a_1}$ is the A_{MSSM} fraction, which is small.

- Further, the low-F points are all such that the other Higgs bosons are fairly heavy, typically above $400~\mathrm{GeV}$ in mass, and essentially inaccessible at both the LHC and all but a $\gtrsim 1~\mathrm{TeV}$ ILC.

General Considerations

- We should note that much of the discussion above regarding Higgs discovery is quite generic. Whether the a is truly the NMSSM CP-odd a_1 or just a lighter Higgs boson into which the SM-like h pair-decays, hadron collider detection of the h in its $h \to aa$ decay mode will be very challenging — only an e^+e^- linear collider can currently guarantee its discovery.

One should note in particular that the CP-violating MSSM CPX and similar scenarios have $h_2 \to h_1 h_1$ decays with $m_{h_1} > 2m_b$ most typical. These scenarios escape LEP constraints not because $h_1 \to \tau^+\tau^-$, but rather because the ZZh_2 coupling is sufficiently suppressed for consistency of the model with the net $Z+b$'s event rate. — At least this is the claim in the preliminary LHWG contour plot presented at SUSY 2005 which shows a 2σ band where the model could live.

- We should perhaps also not take describing the LEP excess and achieving extremely low fine tuning overly seriously.

  Indeed, scenarios with $m_{h_1} > 114~\mathrm{GeV}$ (automatically out of the reach of LEP) begin at a still modest (relative to the MSSM) $F \gtrsim 25$.

  In fact, one can probably push down to as low as $m_{h_1} \gtrsim 108 \div 110~\mathrm{GeV}$ when $m_{a_1} > 2m_b$.

  $\Rightarrow$ must be on the lookout for the $4b$ and $2b2\tau$ final states from h_1 decay, with $h_1 \to 4b$ being the largest when $m_{a_1} > 2m_b$.

- At the LHC, the modes that seem to hold some promise are:

1. $WW \to h_1 \to a_1 a_1 \to b\bar{b}\tau^+\tau^-$.

Our (JFG, Ellwanger, Hugonie, Moretti) work suggested some hope. Experimentalists (esp. D. Zerwas) are working on a fully realistic evaluation but are not that optimistic.

2. $t\bar{t}h_1 \to t\bar{t}a_1a_1 \to t\bar{t}4b$.
   This I imagine will be viable, but analysis is needed.
   Albert de Roeck tells me that the SM analogue of $t\bar{t}2b$ is very much on the edge (as opposed to earlier claims of robustness).
3. Gluino cascades containing $\widetilde{\chi}_2^0 \to h_1\widetilde{\chi}_1^0$.
   It is known that the h_1 can be discovered in such cascades if the production rate for gluinos is large and $h_1 \to b\bar{b}$ is the primary decay. The case of $h_1 \to 4b$ will be harder since the jets are softer, but maybe some signal will survive.
   Indeed, to some approximation (depending on m_{a_1}) the $4b$ state could be analyzed (a la LEP analogy) as though it was a $2b$ final state and such analysis would pick up a significant part of the $2b + 2b$ final state when the b's from one a_1 were fairly collinear.
4. Doubly diffractive $pp \to pph_1$ followed by $h_1 \to a_1a_1 \to 4b$ or $2b2\tau$.
   Would triggering on the $4b$ final state be possible using the muonic decays of the b's?
   These modes are also under consideration by JFG, Khoze, ...

- **At the Tevatron, perhaps the lack of overlapping events and lower background rates might allow some sign of a signal in modes such as Wh_1 and Zh_1 production with $h_1 \to a_1 a_1 \to 4b$ or $2b2\tau$. There is a study underway by G. Huang, Tao Han and collaborators.**

  However, rates are very low and that is even before including reductions from tagging efficiencies and such.

  Conway doesn't believe it can work for expected Tevatron L.

New Dark Matter Scenarios

with McElrath and Hooper

- **The typical low-F scenario has a light a_1 and a $\widetilde\chi_1^0$ that is mainly bino.**
- **The mass of the $\widetilde\chi_1^0$ can be easily adjusted by varying the bino SUSY breaking mass M_1 (with negligible effect on the fine-tuning measure).**

  $\Rightarrow$ new dark matter scenarios with a very light $\widetilde\chi_1^0$ that achieves an appropriate dark matter density based on $\widetilde\chi_1^0\widetilde\chi_1^0 \to a_1 \to X$ annihilation in the early universe.

  $\Rightarrow$ increased need for ILC measurements to verify $\widetilde\chi_1^0$ and a_1 properties with sufficient accuracy to check that it all works.

  Presumably, the best the LHC can do in the case of a light $\widetilde\chi_1^0$ is to upper bound its mass, and information about the a_1 will be confined to its existence and its rough mass.

  Since the annihilation has to be very precisely tuned, only the ILC could provide the needed accuracy on $m_{\widetilde\chi_1^0}$, $\widetilde\chi_1^0$ composition, m_{a_1} and $\cos\theta_{a_1}$.

Conclusions

- The prominent LEP event excess in the $Z + b$'s channel for reconstructed Higgs mass of $m_h \sim 100~\mathrm{GeV}$ is consistent with a scenario in which the ZZh coupling is SM-like but the h decays mainly via $h \to aa \to 4\tau$ or $4j$ (requiring $m_a < 2m_b$) leaving an appropriately reduced rate for $h \to b\bar{b}$.

  This value of m_h for the SM-like h of these scenarios is very attractive from a precision electroweak point of view.

- In contrast, the $Z + b$'s rate predicted if $h \to b\bar{b}$ at a reduced rate and $h \to aa \to b\bar{b}b\bar{b}$ makes up most of the rest is ruled out at better than the 95% CL by the preliminary LHWG analysis unless $m_h \gtrsim 110~\mathrm{GeV}$.

- We strongly encourage the LEP groups to push the analysis of the $Z4\tau$ channel in the hope of either ruling out the $h \to aa \to 4\tau$ scenario, or finding a small excess consistent with it.

  Either a positive or negative result would have very important implications for Higgs searches at the Tevatron and LHC.

- Of course, we cannot ignore the possibility that $m_a < 2m_\tau$ and we must deal with a dominant $h \to 4j$ decay mode.

- Highly non-trivial support for the $h \to aa$ type of scenario derives from the NMSSM. NMSSM models with the smallest fine-tuning typically predict precisely such a scenario with $h = h_1$ and $a = a_1$, with $m_{a_1} < 2m_b$ a distinct possibility.

- We speculate that lowest fine-tuning will be achieved in other supersymmetric models (with a Higgs sector extended beyond the MSSM) for scenarios that have a dominant $h_1 \to a_1 a_1$ (or $h_2 \to h_1 h_1$) decay with m_{a_1} $(m_{h_1}) < 2m_b$. This is simply because the SM-like h_1 (h_2) which is deeply connected to fine-tuning can be lightest in this way.

- We should work hard to see if we can observe or exclude such a Higgs scenario at the Tevatron and eventually the LHC.

  The diffractive Higgs production channel appears to be a very attractive possibility, but rates are small

- The naturally associated dark matter scenario would have an unexpectedly light $\widetilde{\chi}_1^0$. Its properties and those of the a_1 would need to be determined precisely to check consistency of the dark matter relic density with accelerator data.

- It seems quite certain that ILC precision data will be essential for all but the most basic detection of a few Higgs events and for checking the dark matter abundance if a light $\widetilde{\chi}_1^0$ with $2m_{\widetilde{\chi}_1^0} \sim m_{a_1}$ is found.

- If $m_{a_1} < 2m_\tau$, probably the diffractive channel will the only game in LHC town. But would we believe a jets only signal, and will it have more background?

  I am guessing we would need to await the ILC.

- At the LHC, perturbative $WW \to WW$ might in the worst of cases, $a_1 \to jj$, be our only hint, other than precision EW, that there is a light Higgs.