No Higgs with 10 fb^{-1}: Implications for SUSY

Tim M.P. Tait

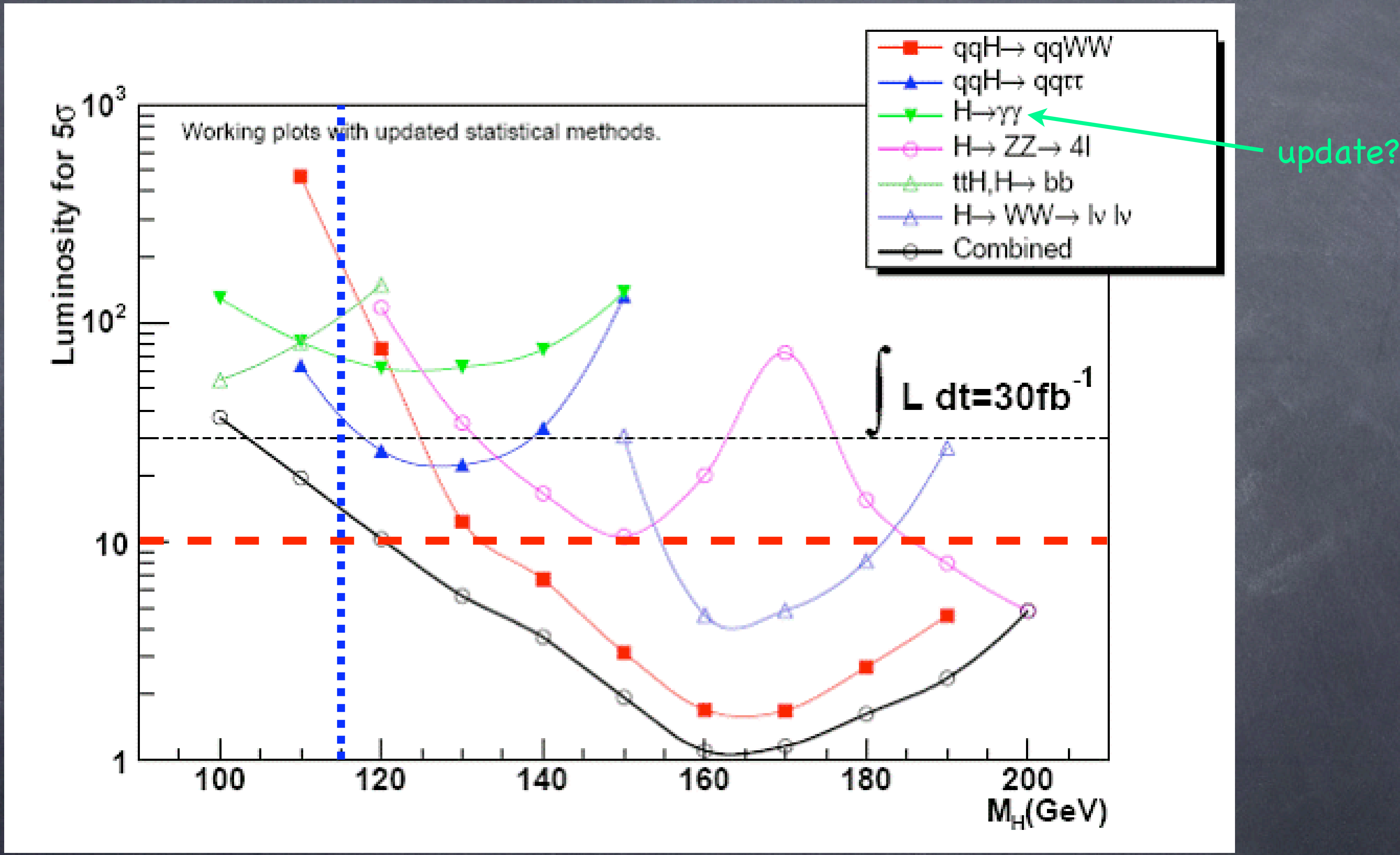
Argonne National Laboratory

LHC/ILC @ FNAL
April 12, 2007

Outline

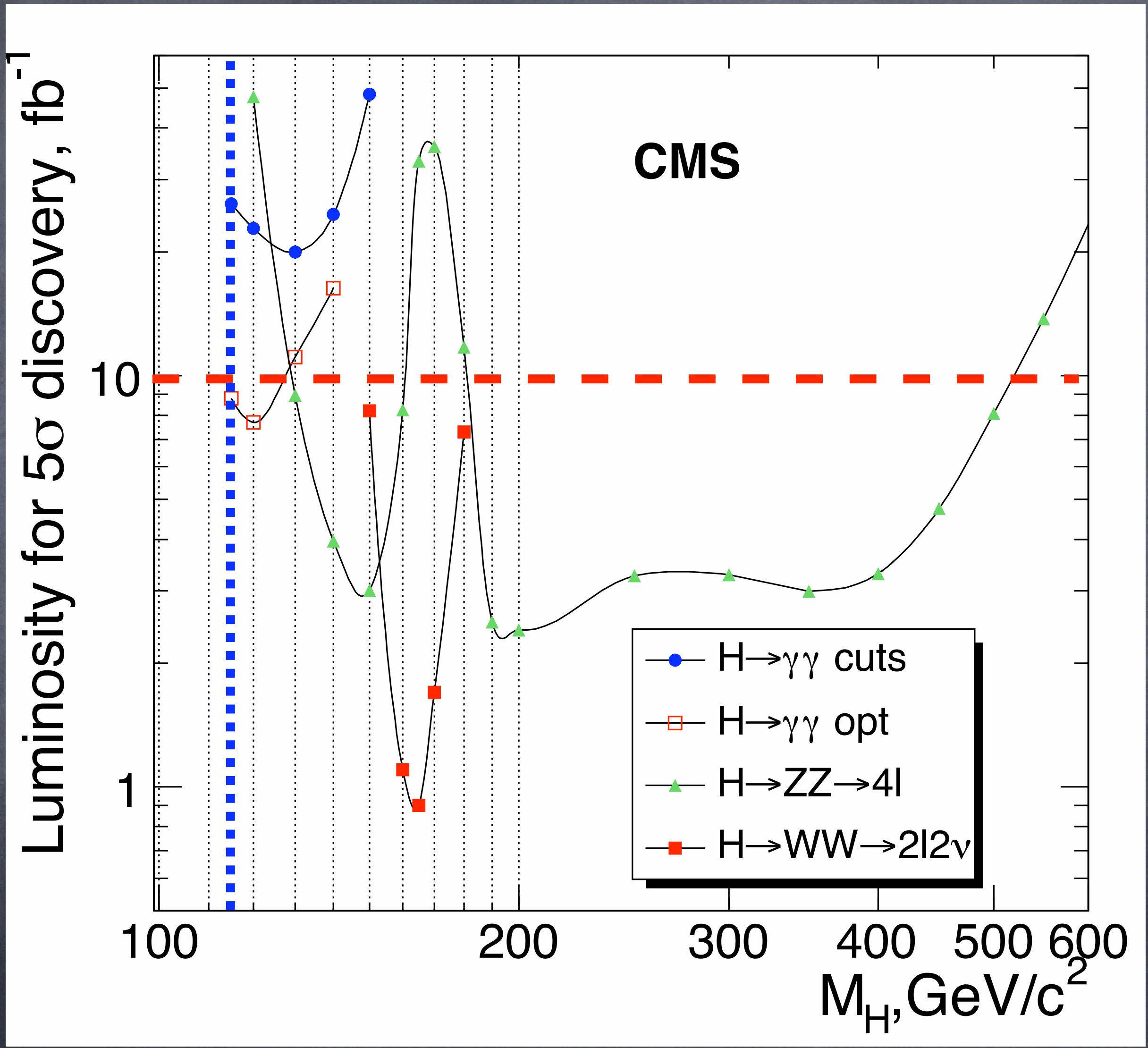
- Higgs Searches with 10 fb^{-1}.
- What it means for the Higgs if we haven't seen it.
- What it means for SUSY.
- Some examples of how this could happen.
- How the ILC can help.

The ATLAS Picture



SM Higgs with m_h > 120 GeV discovered
(with multiple channels combined).

The CMS Picture



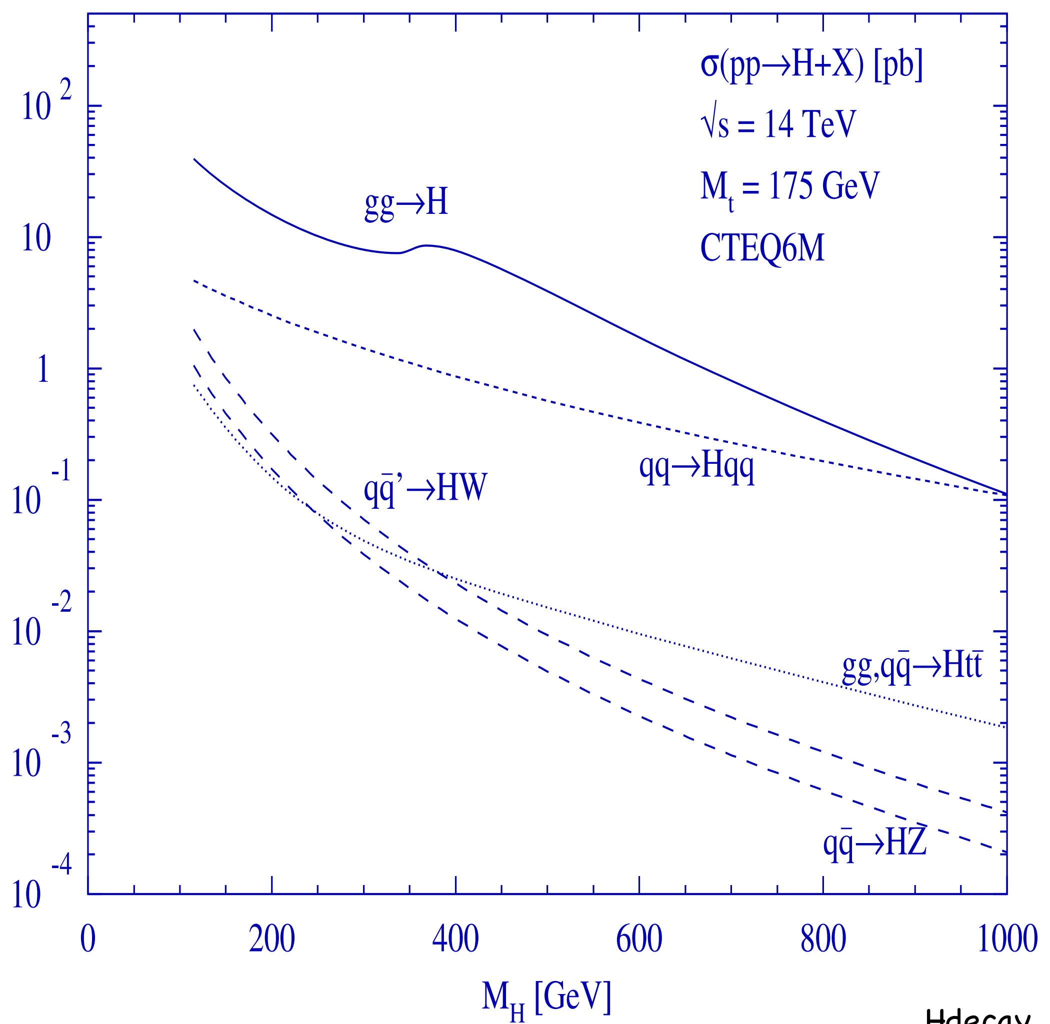
WBF
not shown

Single channel coverage of essentially any SM Higgs

SM Higgs Search

- So if a SM-like Higgs is there (and all goes well) at 10 fb^{-1}, we should see it.
- Sometimes more than one channel is needed, and sometimes 5σ is right at the 10 fb^{-1} point.
- So the specifics of detector performance, background estimates, etc will be crucial to realize discovery in 10 fb^{-1}.
- Essentially, not seeing the Higgs with 10 fb^{-1} is equivalent to the statement that the Higgs is not SM-like.

SM Higgs Production

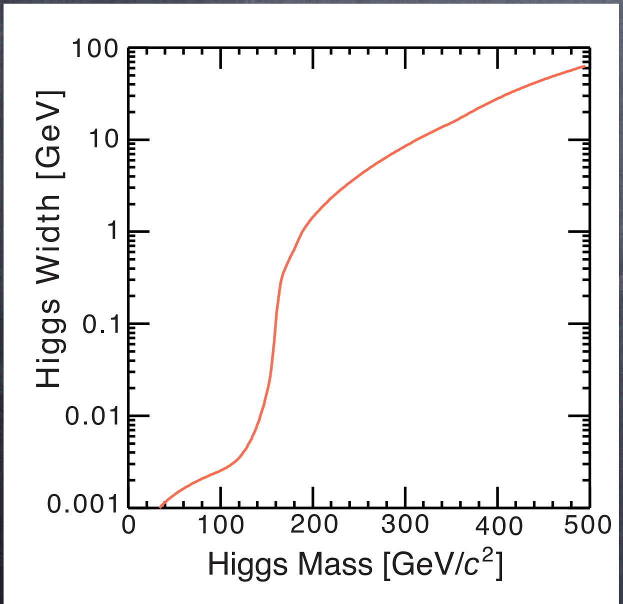


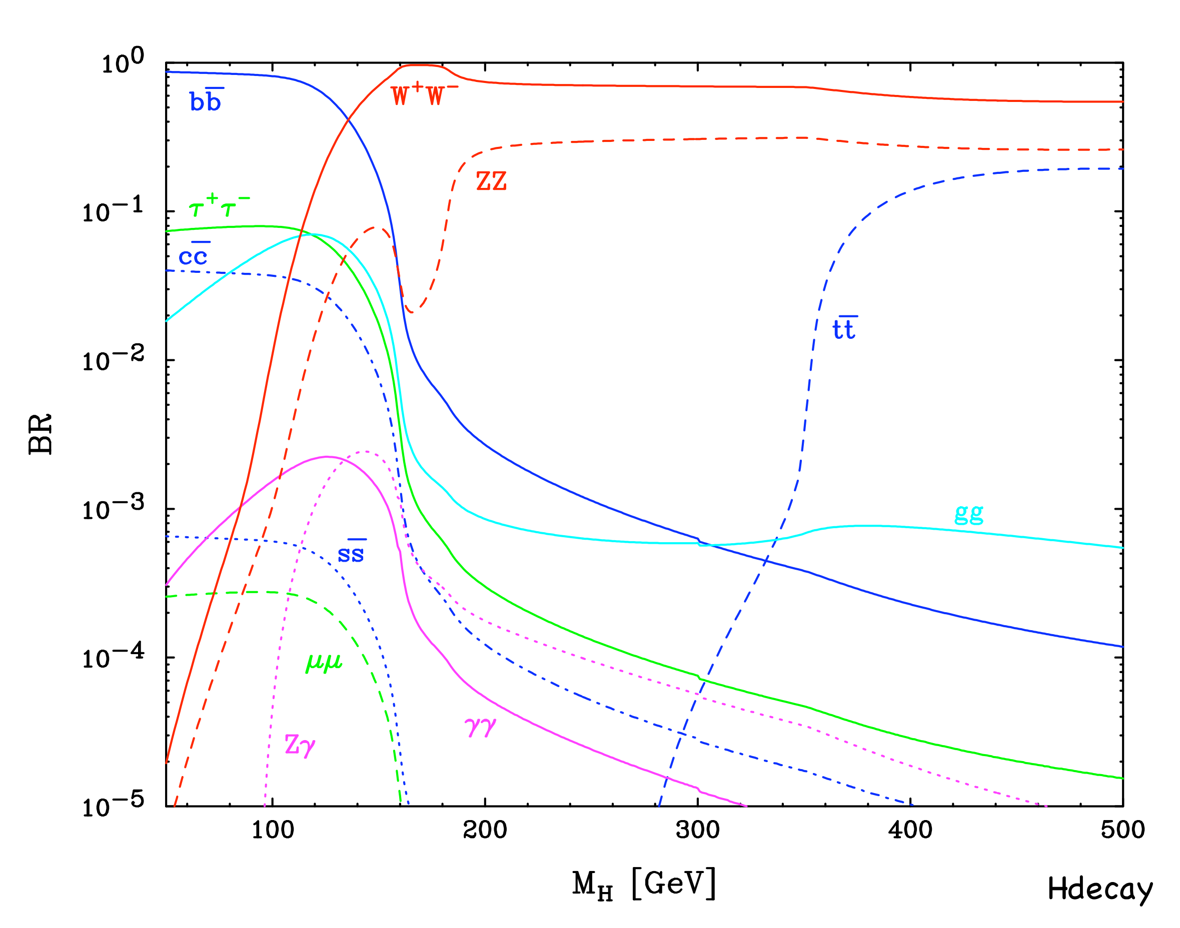
Hdecay

- Many searches make use of the gg -> H inclusive production mode.
- This mode is driven by the loop-induced coupling of H-g-g and is thus sensitive to new physics.

SM Branching Ratios

- At low masses, H-> bb dominates.
- The width is small at low masses, leaving room for new physics to change the BR's significantly!





Hiding the Higgs

- To hide the Higgs, we can:
  - Mix it with some other scalar so it doesn't look SM-like.
  - Reduce its production cross section.
    - This is not too shocking, the dominant production was a loop process, so its sensitive to new physics.
  - Decrease its branching ratios into observable modes.
    - Also not shocking.. < 135 GeV the width is tiny, so sensitive to new physics.
    - But new particles might be visible anyway...

The SUSY Higgs

- There are two complications in going from the SM Higgs searches to the MSSM.
- The MSSM is a two-Higgs doublet model. The EWSB VEV can be shared among two CP-even Higgs states.
- In the MSSM the Higgs quartic interaction is fixed by SUSY to be equal to the EW gauge couplings. (So this is one case where the SM has more freedom than the MSSM). This is the origin of the famous tree-level relation: $M_h \leq M_Z$
- Including large loop corrections from top and stop, it is still very hard to get past ~ 130 GeV.

Hiding the SUSY Higgs

- Zeroth order: m_h < 130 GeV : The MSSM is covered!
  - So no Higgs means no MSSM.
- First order: The MSSM could allow for a new decay mode like H -> super-partners. (More on that later).
  - We could also consider the two Higgs doublet model effects, but that probably won't change our conclusions.
- Second order: It could be SUSY, but it might not be the minimal model. The strong assumptions that made the MSSM minimal were actually in the Higgs sector, so it wouldn't be too shocking if that was where the model might break down.

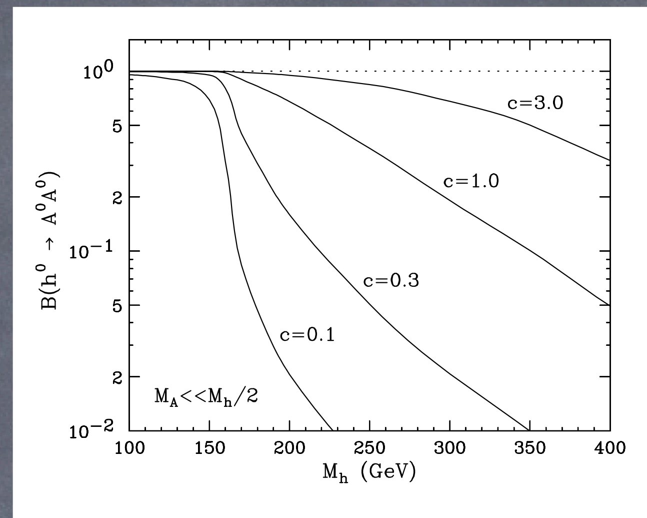
Non-minimal SUSY

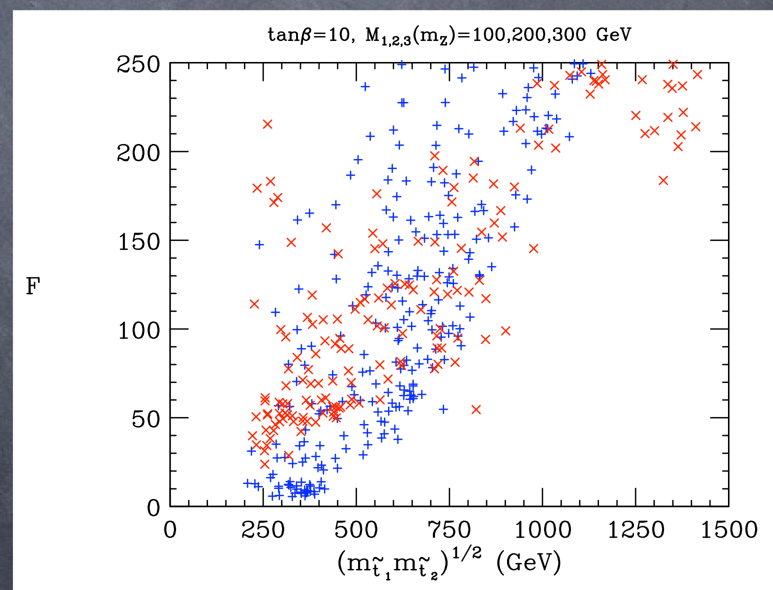
- Many extensions of the MSSM (NMSSM, Fat Higgs, Gauge extensions, ...) raise the SM-like Higgs mass by adding new contributions to the Higgs quartic.
- That is interesting (and different) but it usually makes the Higgs **easier** to find by opening up the ZZ and WW channels.
- They generically contain new ingredients which might allow for new decay modes.
- One popular one is the NSSM. There is a new CP-even (n) and a new CP-odd (a) scalar. If a is light enough, we may have H->aa dominant.

H -> aa

Dobrescu, Landsberg, Matchev
PRD63, 075003 (2001)

- The question becomes: how does the a decay?
- The a decay will depend a lot on the a mass.
- Popular choices are:
  - $m_a > 2\ m_b$ (a->bb)
  - $2\ m_b > m_a > 2\ m_\tau$ (a->ττ)
  - $m_a < 2\ m_\tau$ (a->γγ can be important - the a's are highly boosted and each a can thus look like **one** photon).





+: BR(H->ττττ) > 0.9
×: mH > 114 GeV

Dermisek, Gunion PRL95, 041801 (2005)

H Decay to Neutralini

- If the lightest neutralino is light enough, the Higgs could decay into it. Assuming R-parity is conserved, this is an invisible decay mode for the Higgs.

- It has been proposed to search for such a Higgs using weak boson fusion. The idea is that the rapidity gap of the associated jets provides something to tag on.

- With 10 fb^{-1}, an invisible BR down to of order 10% can be probed assuming a standard WBF production σ.

M_H (GeV)	110	120	130	150	200	300	400
10 fb^{-1}	12.6%	13.0%	13.3%	14.1%	16.3%	22.3%	30.8%
100 fb^{-1}	4.8%	4.9%	5.1%	5.3%	6.2%	8.5%	11.7%

TABLE IV. Invisible branching ratio that can be probed at 95% CL as a function of M_H for an integrated luminosity of 10 fb^{-1} and 100 fb^{-1}. A SM production cross section is assumed.

If R-parity is not conserved, the Higgs can decay into six jets!

Eboli, Zeppenfeld PLB495, 147 (2000)

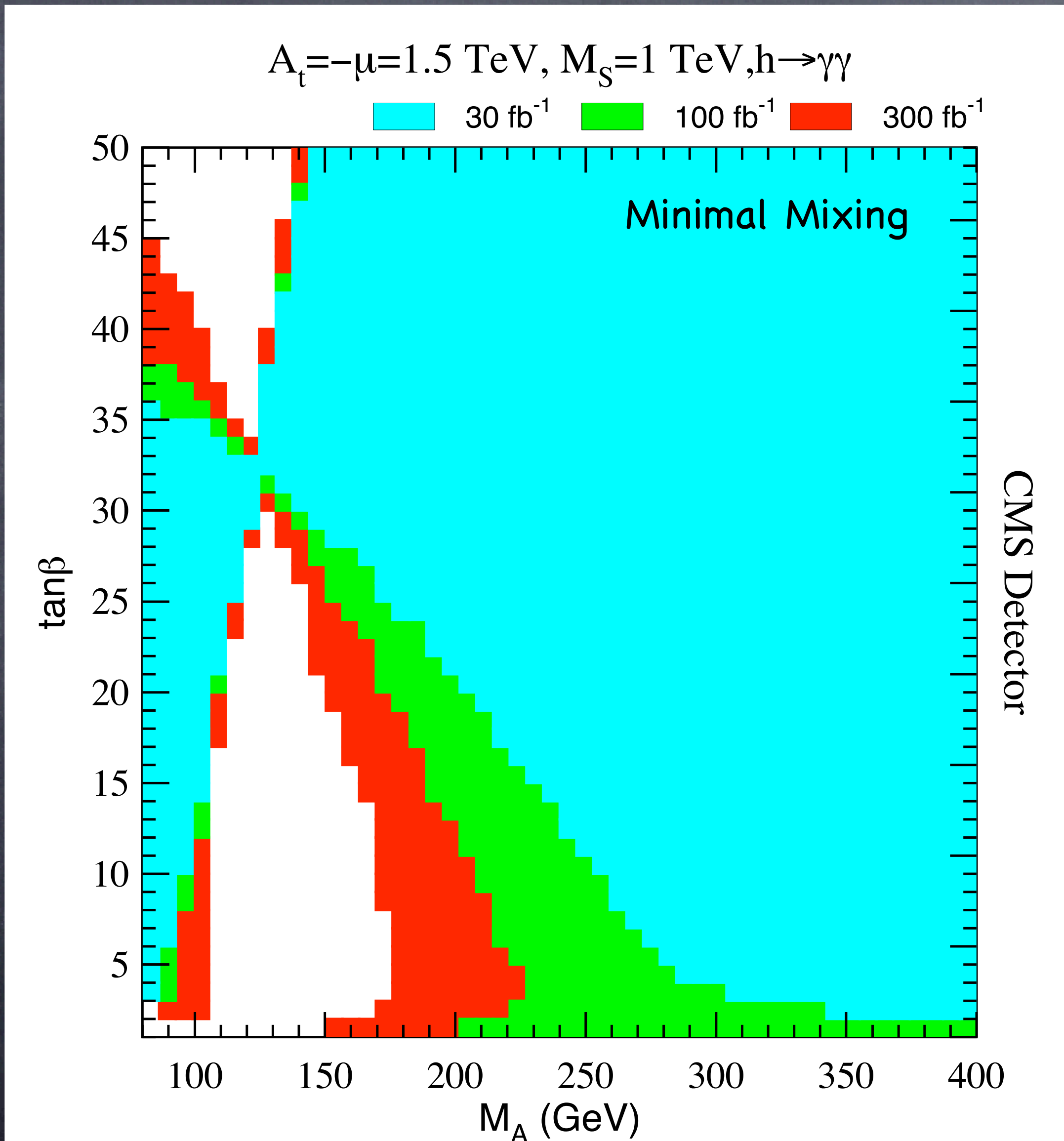
Datta, Konar, Mukhopadhyaya PRD63, 095009 (2001)

Carpenter, Kaplan, Rhee hep-ph/0607204

Low M_A

- When $M_A >> M_Z$, the two Higgs doublet model part of the MSSM goes into a decoupling limit, and the lightest CP even Higgs becomes very SM-like.
- When $M_A \sim M_Z$, life gets more interesting. The two CP-even Higgses can share the VEV, and their couplings to SM fields are both non-standard.
- However, the low M_A implies that the SUSY Higgses become easier to see, because their masses are all of order M_A.
- So this regime has interesting and non-SM Higgs physics, but it does not very effectively hide the Higgs, except perhaps for some interesting regimes of parameters.

Low M_A and h->γγ



Other channels and/or other Higgses are still usually visible.

Carena, Mrenna, Wagner PRD62, 055008 (2000)

H -> jets!

- To finish up, let me consider the possibility that the Higgs decays into light (unflavored) jets.
- This is a general possibility for a low mass Higgs, because the width into SM particles is so small, it is easily overwhelmed.
- An example comes from the MSSM itself, with the (radical) assumption that the lightest sbottom is a few GeV.
- If R-parity is violated, the sbottom can decay into highly collimated quarks, looking like a single jet most of the time.
- If the sbottom is an appropriate mixture of left- and right-"handed" sbottom, it decouples from the Z boson, avoiding LEP I constraints.

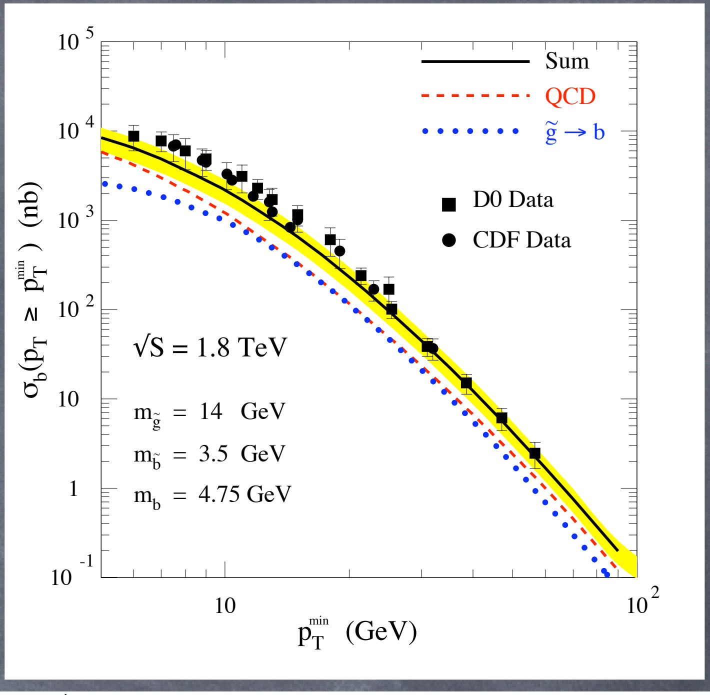
Carena, Heinemeyer, Wagner, Weiglein PRL86,4463 (2001)

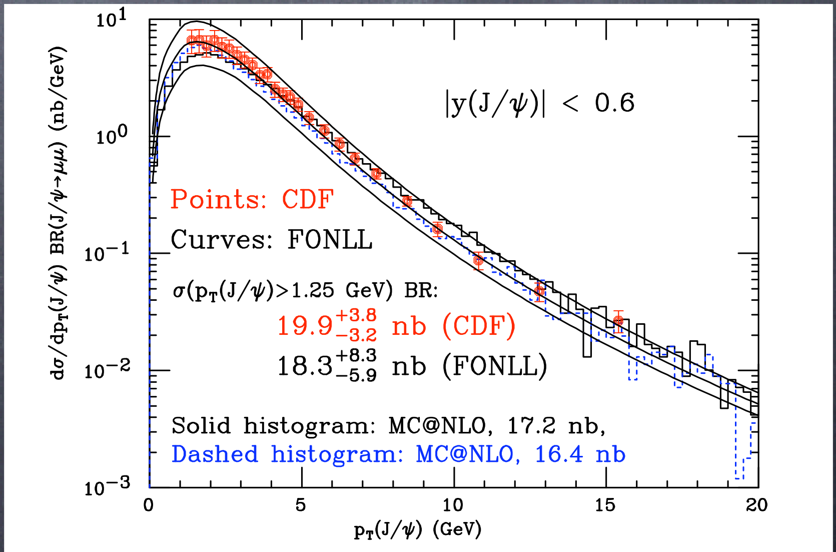
- It has a small impact on all other low energy data

Pre-History

Berger, Harris, Kaplan, Sullivan, Tait, Wagner PRL86, 4231 (2001)

- Around 2000, there had been a long history of the open bottom production cross section being measured to be a factor of about 2 higher than the QCD prediction.
- Light sbottoms together with gluinos of mass around 15 GeV could solve the mystery.
- Since then, QCD has done a better job of predicting the data. This removes the original motivation, but not the possibility that light sbottoms are allowed.



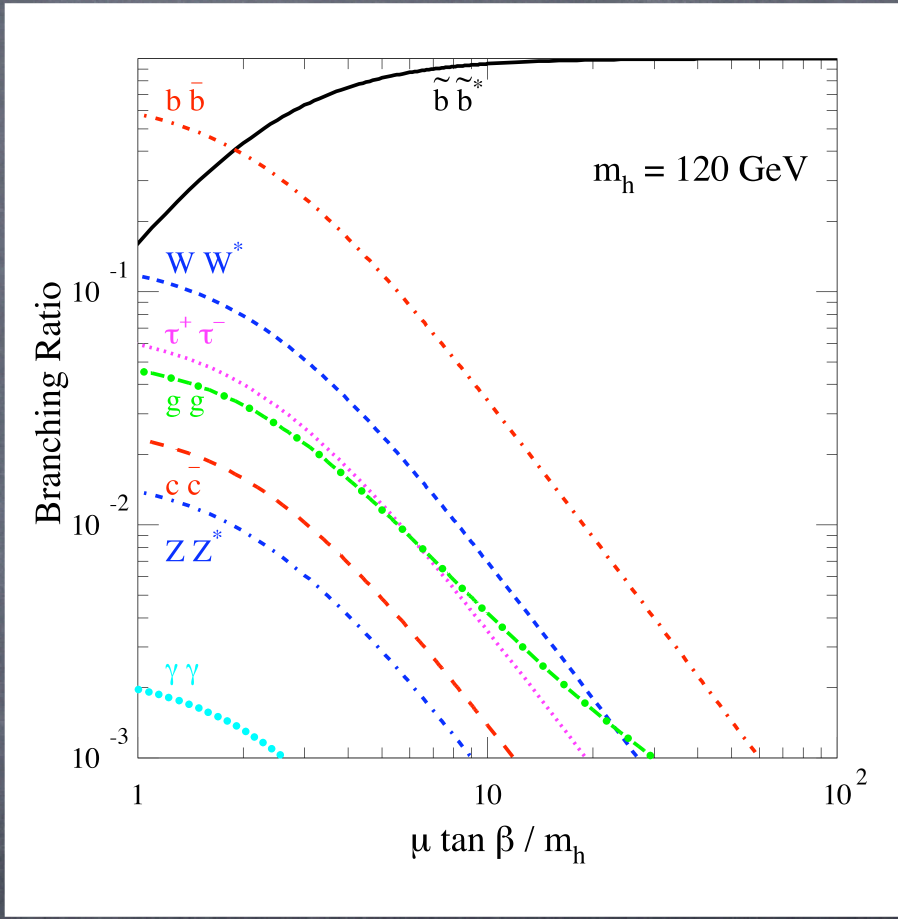


Mangano (et al), hep-ph/0411020

"These aren't the light sbottoms you're looking for…"

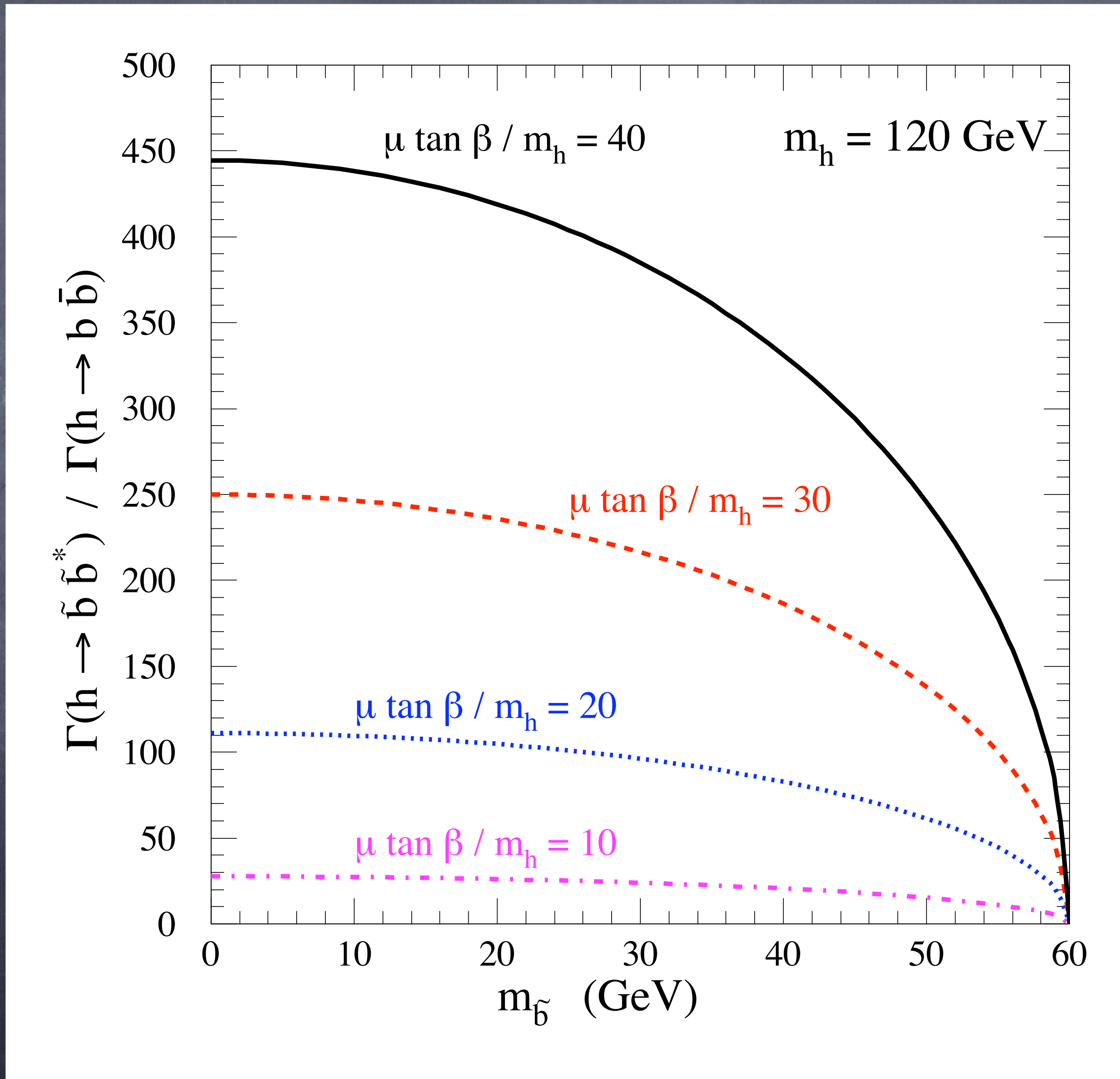
H->jets

- So, while light sbottoms may not be as exciting as they once were, let's see what they do to Higgs physics.
- We continue with the idea that they decay through R-parity violating interactions into collimated quarks, looking like a single jet.
- If they are light enough for the Higgs to decay into them, the BR is controlled by ($\mu \tan\beta / m_h$).
- Note that this is even true in the "decoupling" (large M_A) regime! The sbottom is not a SM particle and its Higgs coupling doesn't asymptote to a SM quantity.



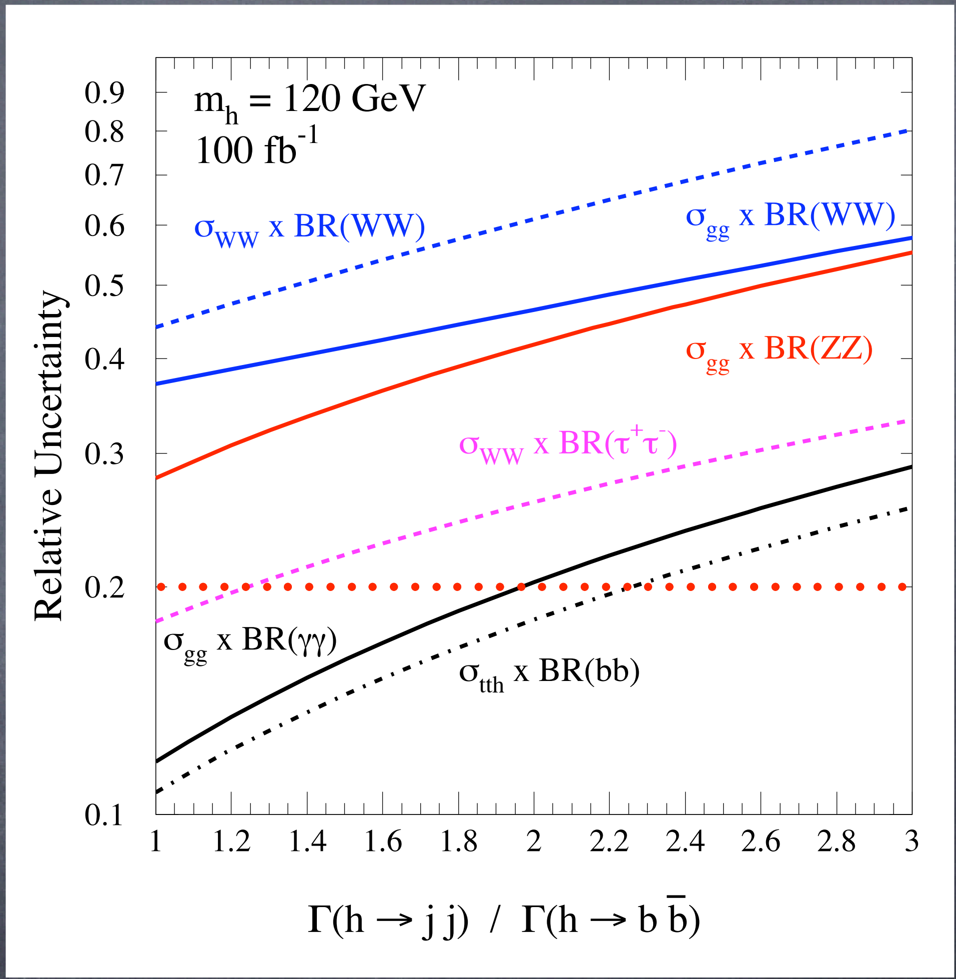
Berger, Chiang, Jiang, Tait, Wagner
PRDD66, 095001 (2002)

Different Sbottom Masses



At the LHC

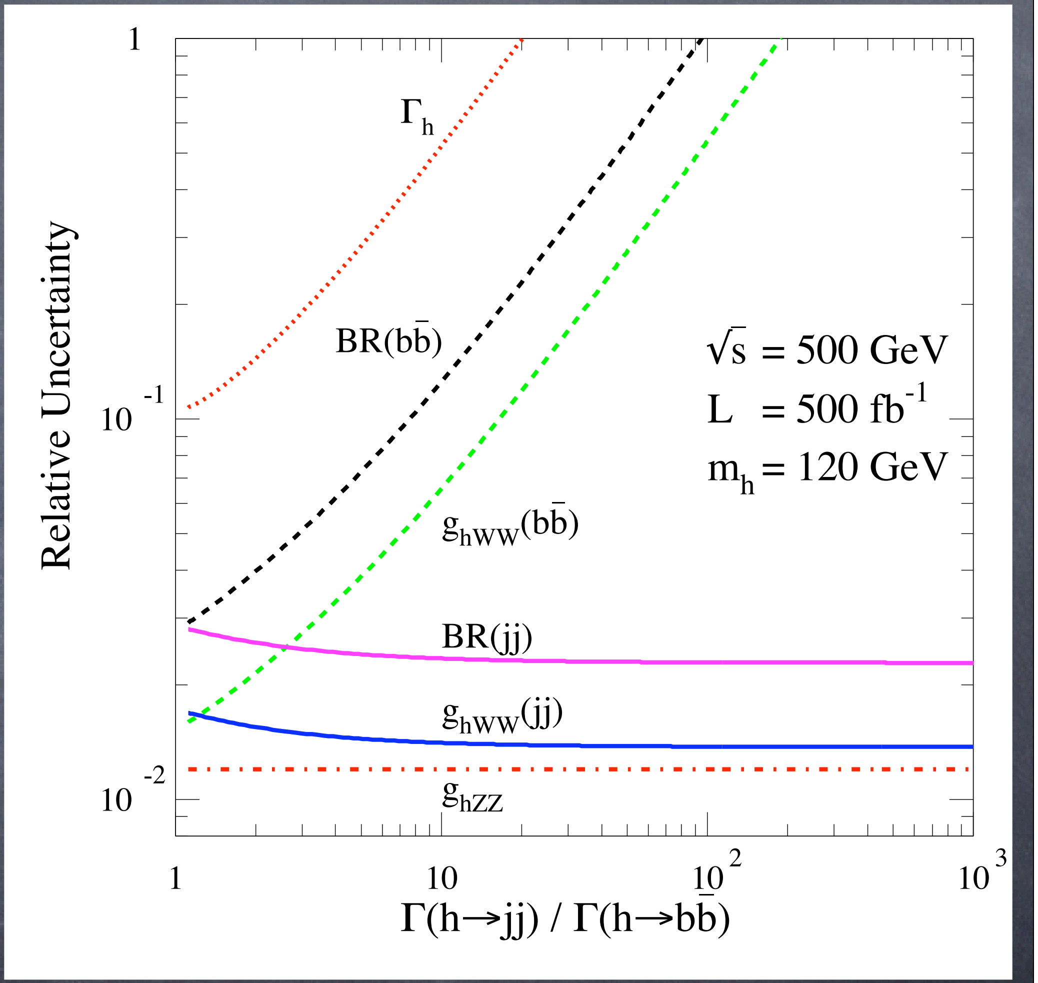
- The effect on a given channel at the LHC is somewhat complicated; the sbottoms dominate decays, and modify the H-g-g and H-γ-γ couplings.
- For Higgs masses in the SUSY range, once the BR into jets is a few times that into b's, the LHC essentially loses the ability to discover the Higgs.
- Carlos's plenary talk has more details (I think!).



Berger, Chiang, Jiang, Tait, Wagner
PRDD66, 095001 (2002)

The ILC can help!

- A (light) Higgs with a large branching ratio into jets is a challenge for the LHC because of backgrounds.
- The ILC can still discover the Higgs using the recoil method, and make many key measurements, especially the Higgs couplings to the weak bosons.
- This may be an example where the ILC would have been helpful for the LHC than vice versa.



Berger, Chiang, Jiang, Tait, Wagner
PRDD66, 095001 (2002)

Outlook

- The minimal supersymmetric standard model usually results in a light (< 130 GeV) Higgs. With 10 fb^{-1} the current projections are that we will find it.
- However, there are interesting, allowed regions of parameter space even in the MSSM in which the Higgs decays in a way which the LHC finds difficult to deal with.
- Non-minimal models allow for more exotic decays, some of which are easy, some are challenging, and some we just don't know about.
- The ILC can help a lot with difficult cases, and it can contribute even when the LHC finds the Higgs easily.

Supplemental Slides

Heavier Higgs at the LHC