Looking For A (Nonstandard) Higgs Below 114 GeV at LHC

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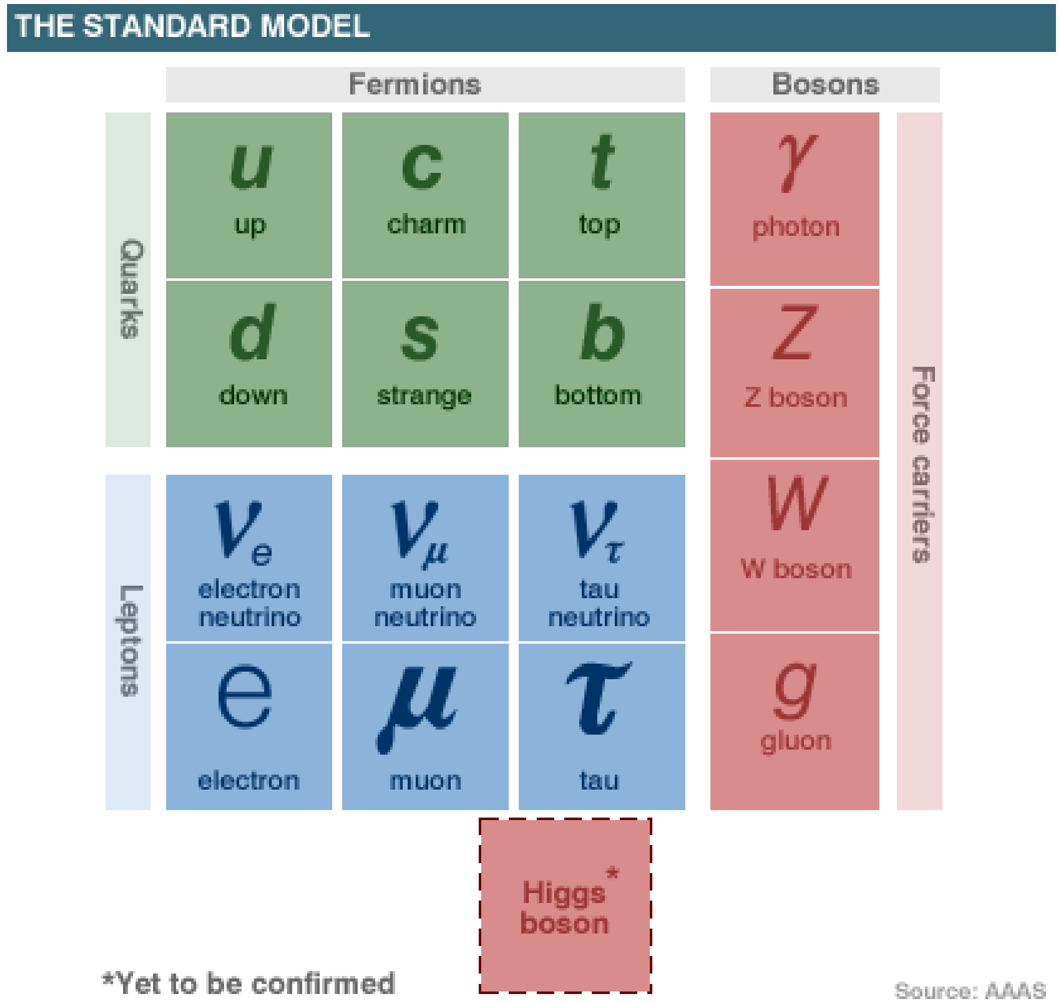
SLAC Atlas Forum 2/28/07

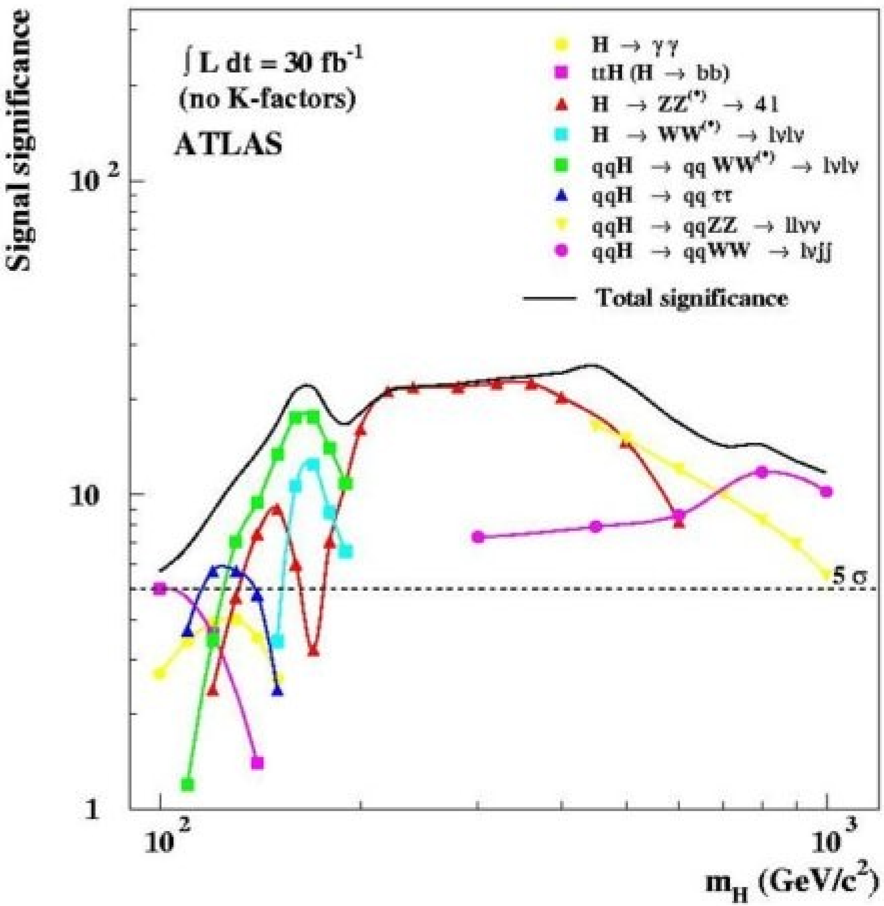
SC, P.J. Fox, N. Weiner hep-ph/0608310, accepted PRL
SC, N. Weiner work in progress

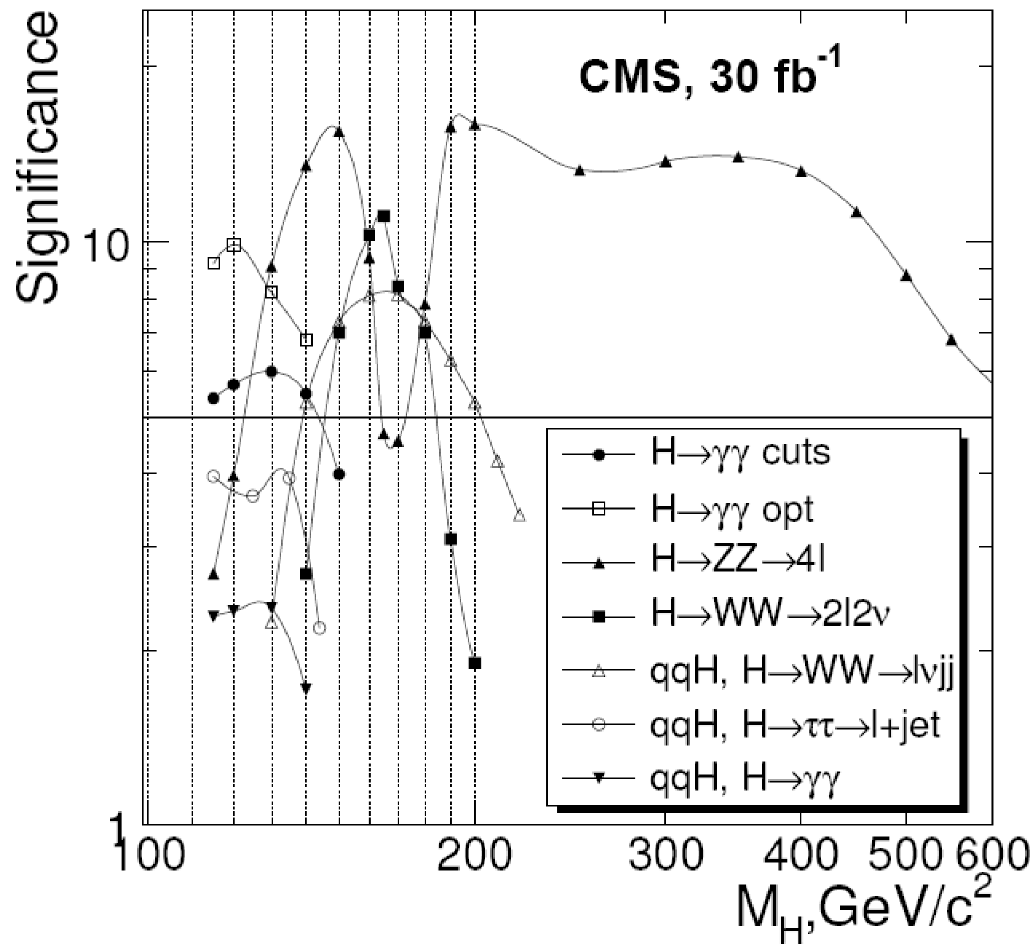
Where is the Higgs Boson?

- Missing Ingredient of Standard Model
- Comprehensive LEP search, mass limit > 114 GeV
- Must find it!!! Completes theory of Electroweak Symmetry Breaking (EWSB)
- Now up to Tevatron and LHC



Large Hadron Collider





Higgs Search has predicated design of Atlas/CMS for full coverage

SM Higgs Search Timeline

- Acquire luminosity, search in relevant channels, get 5σ discovery
- Measure mass, decay width, couplings, CP properties whenever possible
- Publish results for adoring scientists and public
- Await Nobel committee

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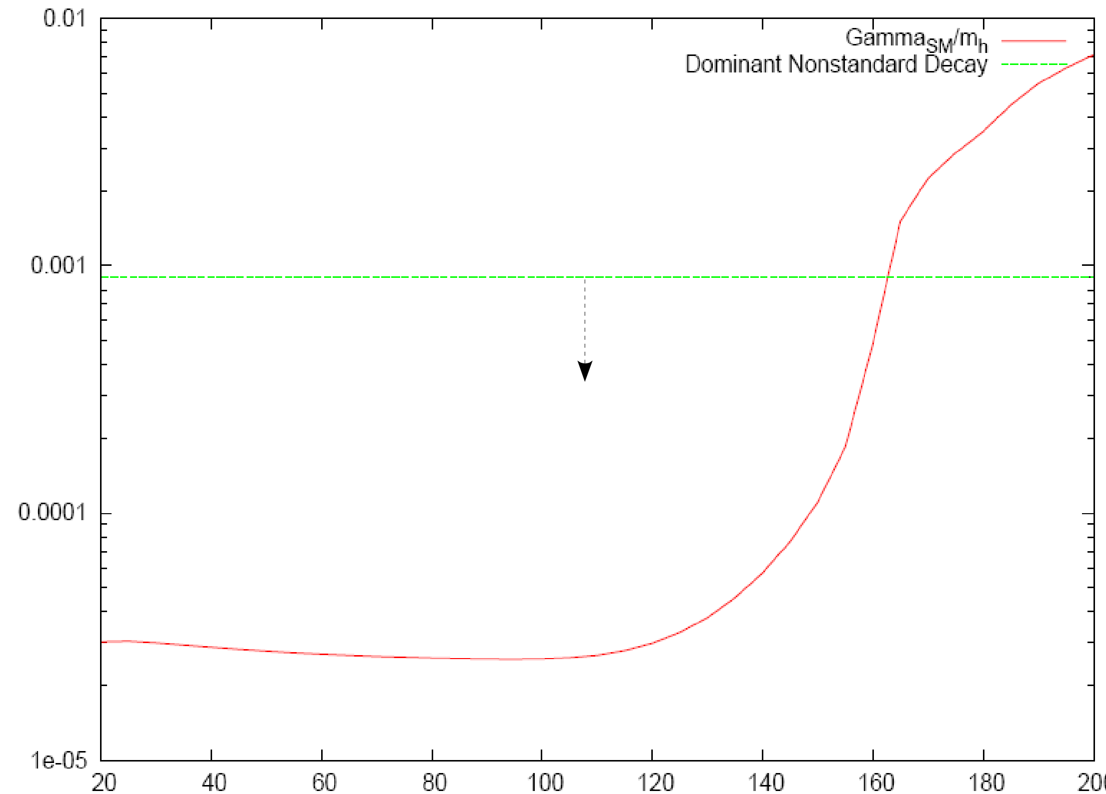
- But what if it isn't a Standard Model Higgs?

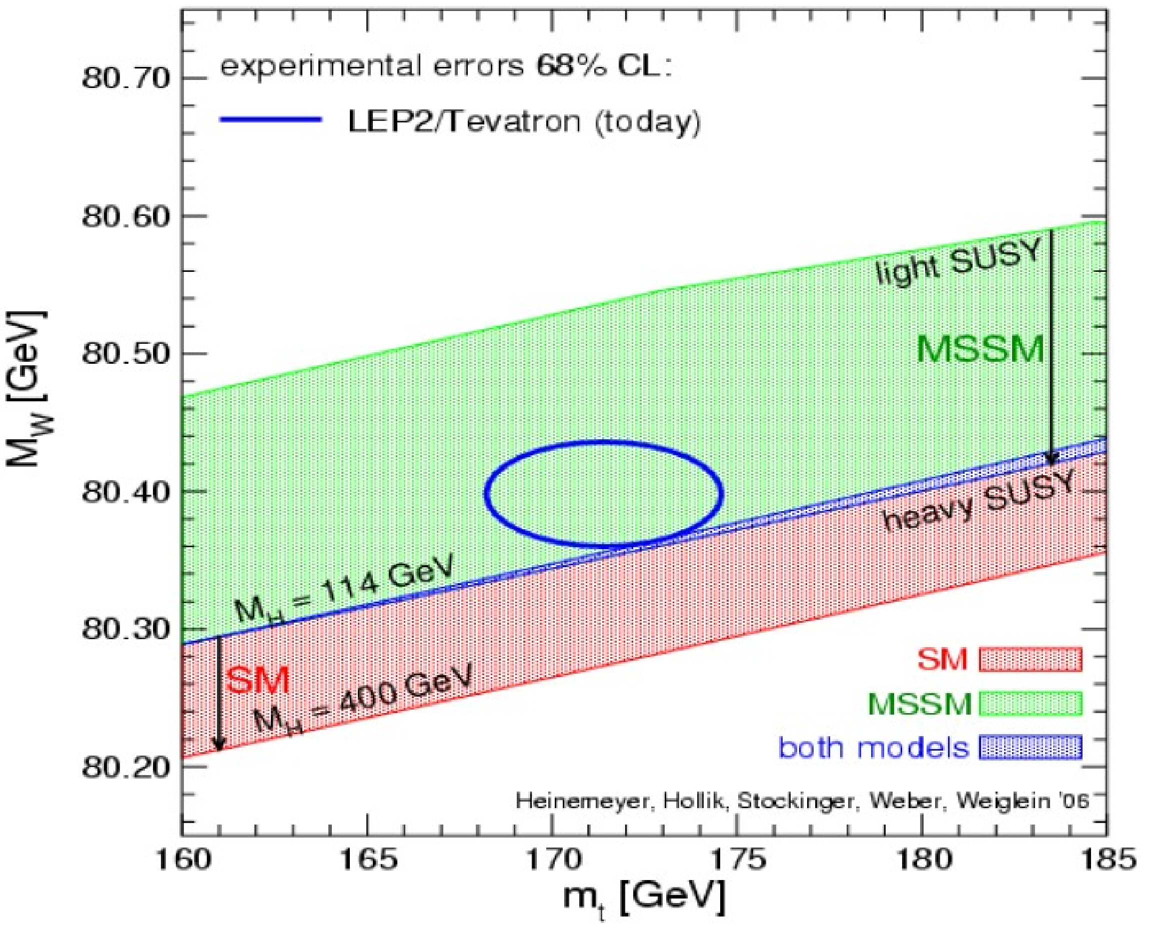
Extending the lamppost: A particular class of nonstandard Higgs

- A Higgs with standard couplings to SM fields, but nonstandard through couplings to new light fields
- New decay channels for the Higgs, now the dominant decay?
- Only possible below WW threshold



$$BR(h \rightarrow SM) = \frac{\Gamma_{SM}}{\Gamma_{SM} + \Gamma_{New}}$$

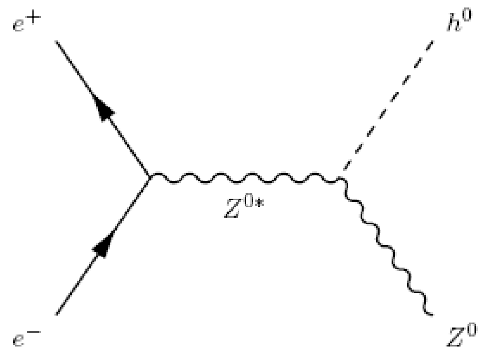
Corroborating Hints?



Preliminary inclusion of CDF Run-II W mass

- Experimental – Precision electroweak observables (top, W) $m_h < 166$ GeV
- Theoretical – Light Higgses natural in BTSM theories (e.g. % level tuning for > 114 GeV in SUSY)

LEP Higgs Search



$$e^+ e^- \to Z\, h$$

LEP comprehensively constrained two body Higgs decays → nonstandard decays needed to evade LEP2 limit

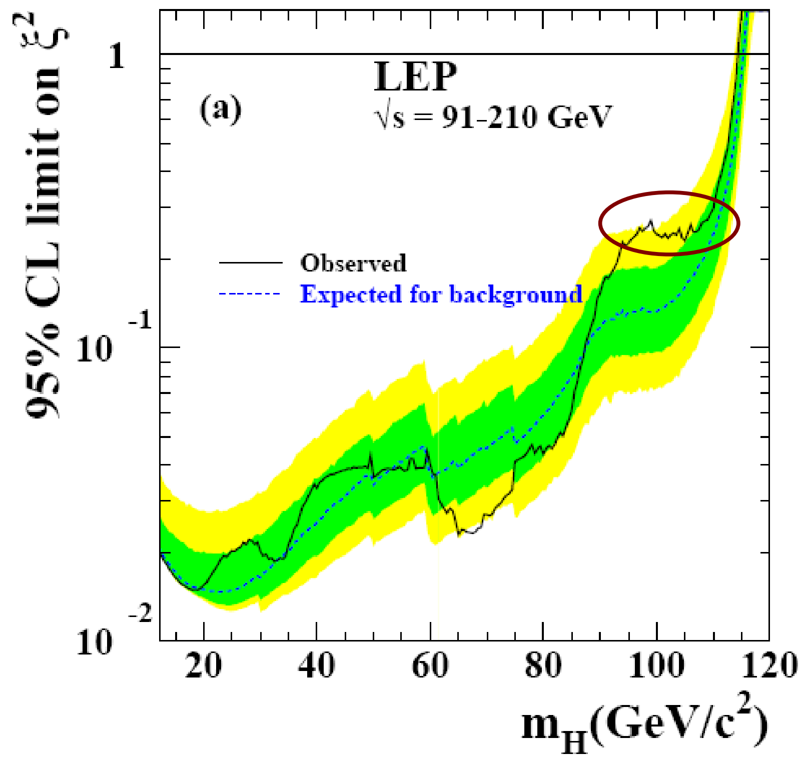
fermion-antifermion: b quarks, taus, light quarks

gauge boson pair: WW, ZZ, photons, gluons

nonstandard: invisible decays, scalar cascades

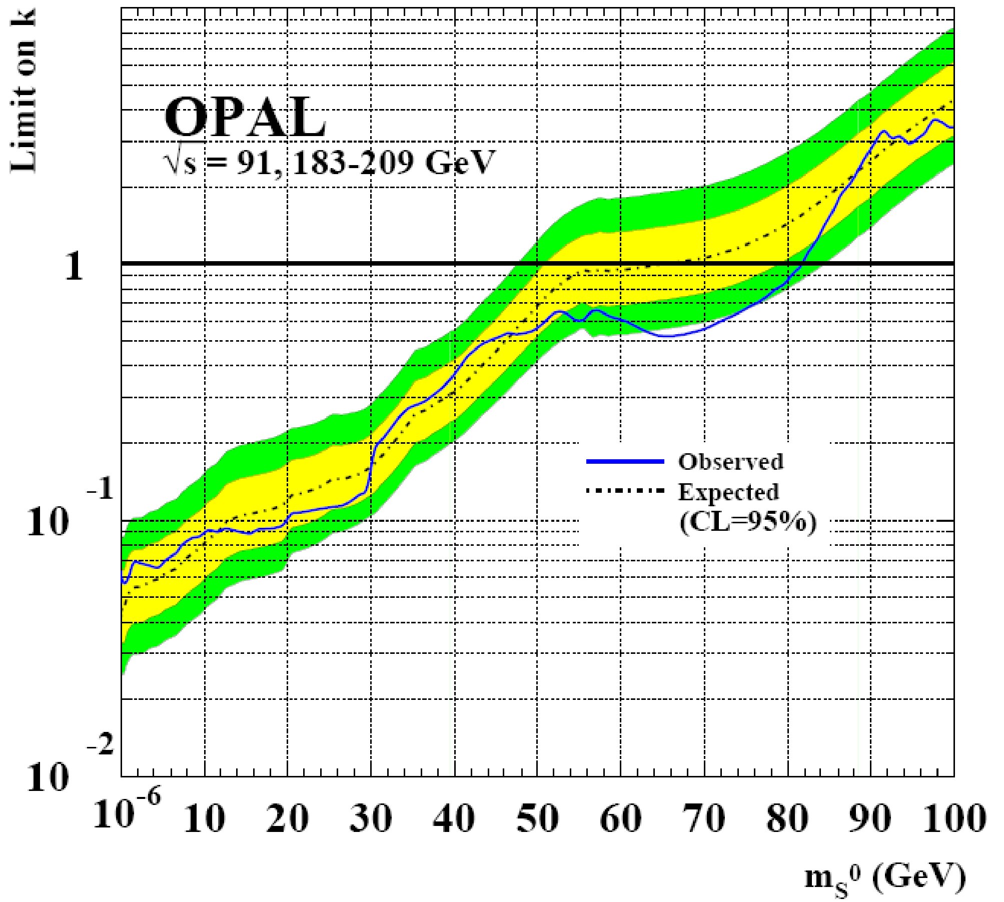
SM Discovery Delayed?

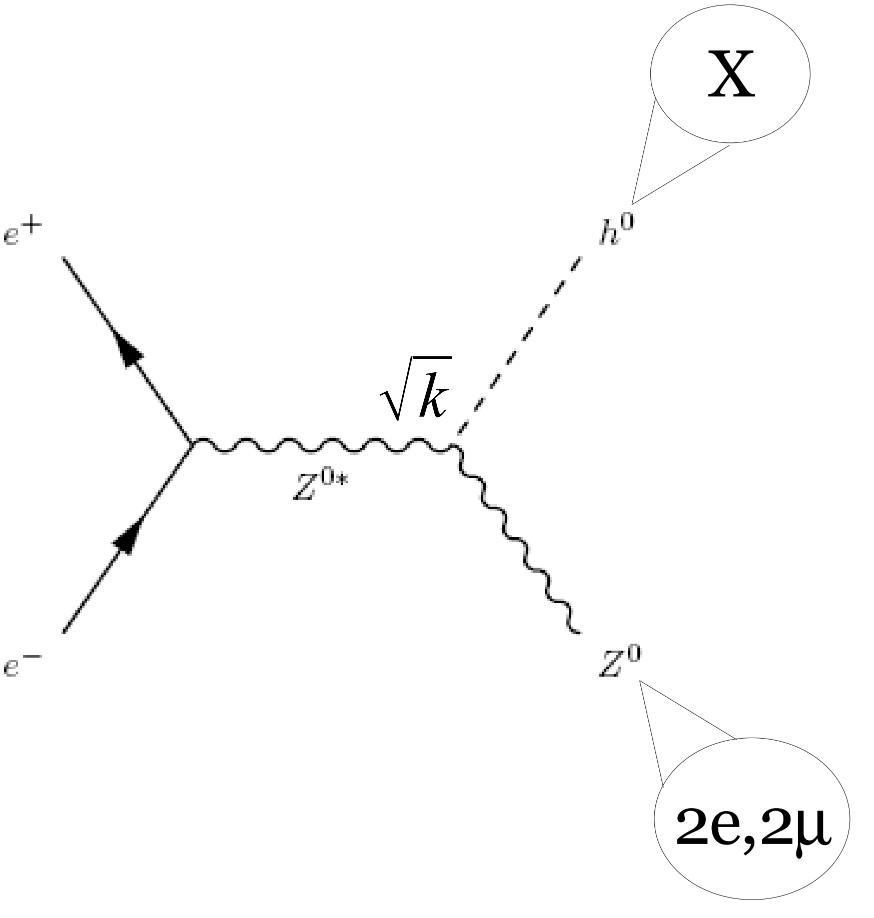
- For a 100 GeV Higgs, Br(h→SM) < .2 (LEP2), lumnosity needed for SM search increases by $1/Br(h \to SM)^2$
- Roughly, necessary $\mathcal{L}_{int}$ > 25*20 fb^{-1}~ 500 fb^{-1}→SLHC



- O(1) modes should be looked for if possible
  - Discover Higgs quicker
  - Discover the new states
  - Hints of BTSM theory?

LEP Constraints – Decay Independent

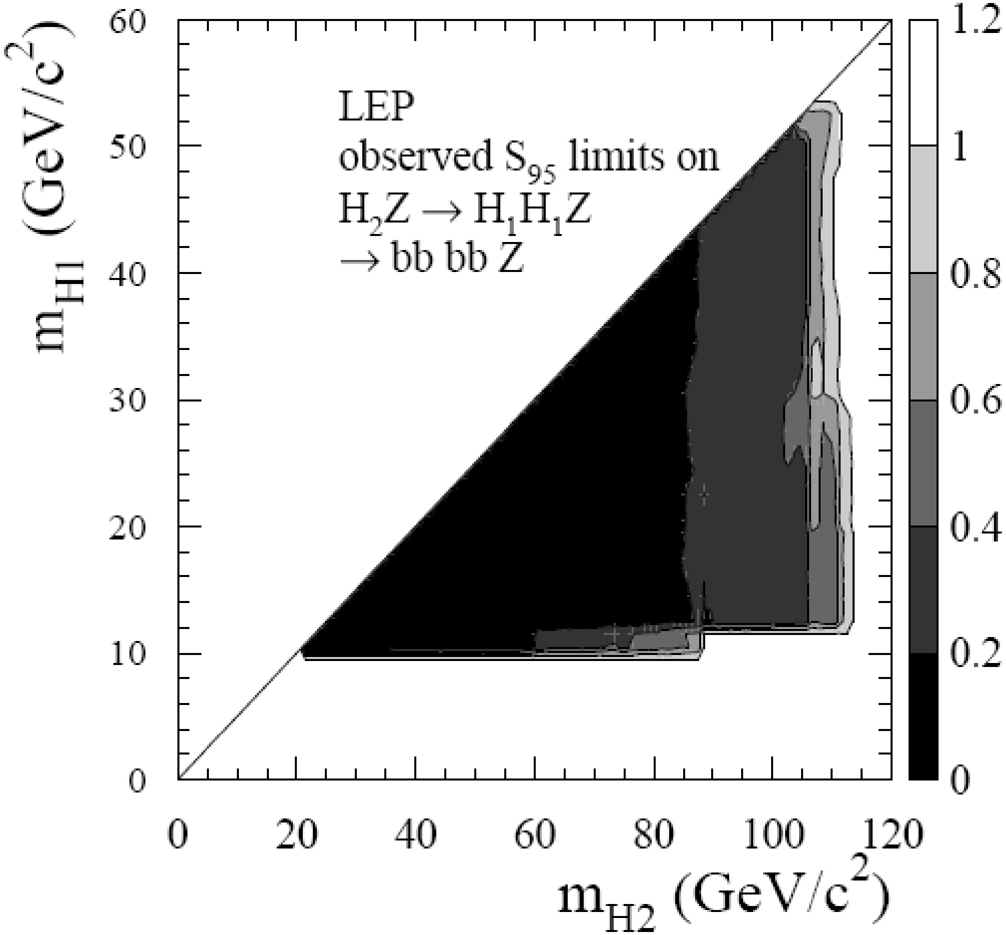


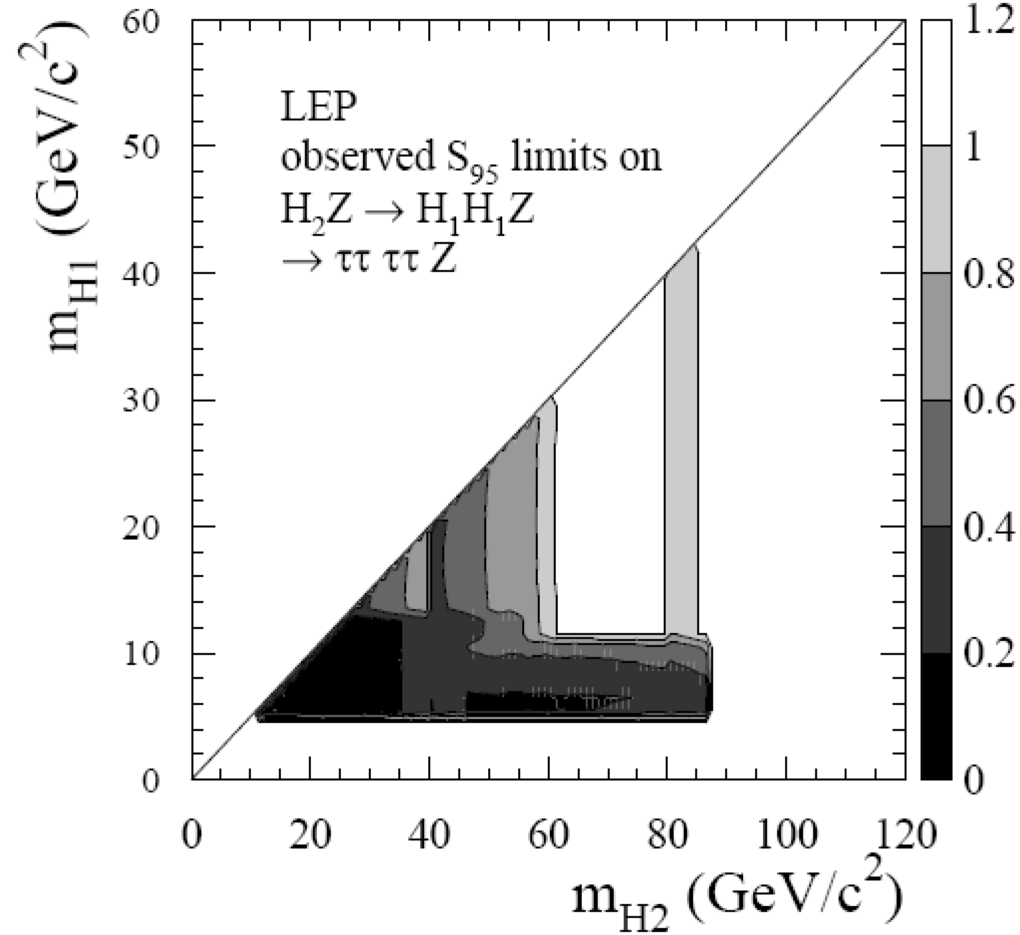


Reconstruct Z from electrons or muons, "Higgs" mass from missing momentum vector

95% CL limit Mh > 82 GeV

Scalar Cascades in Fashion





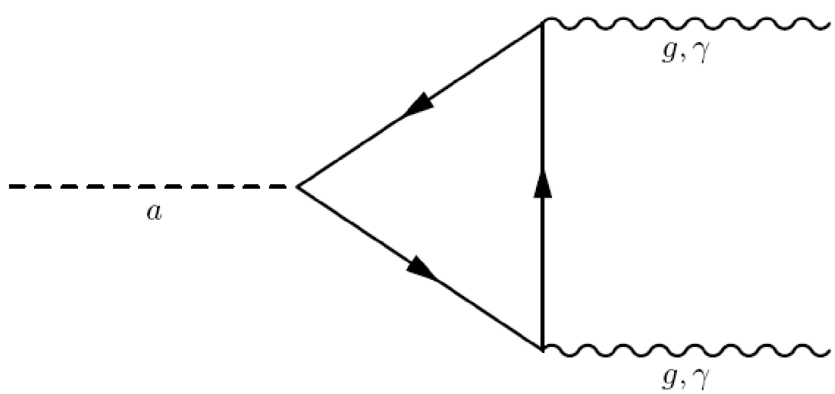
Motivated by natural EWSB in SUSY models (Gunion et.al.)

Potential Searches: h→2j 2τ (Gunion et.al.), h→4τ (Graham et.al.)

A New Possibility

Dobrescu et.al. &
SC, Fox, Weiner

- $h \rightarrow 2a$, with massless gauge boson cascade, $a \rightarrow 2g, 2\gamma$
- $h \rightarrow 4$gluons is difficult. However, often accompanied by $h \rightarrow 2g\ 2\gamma$ or 4γ



- Natural "SU(5)" Branching Ratios

4g	~ 1
2g 2γ	$\sim 7\times10^{-3}$
4γ	$\sim 10^{-5}$

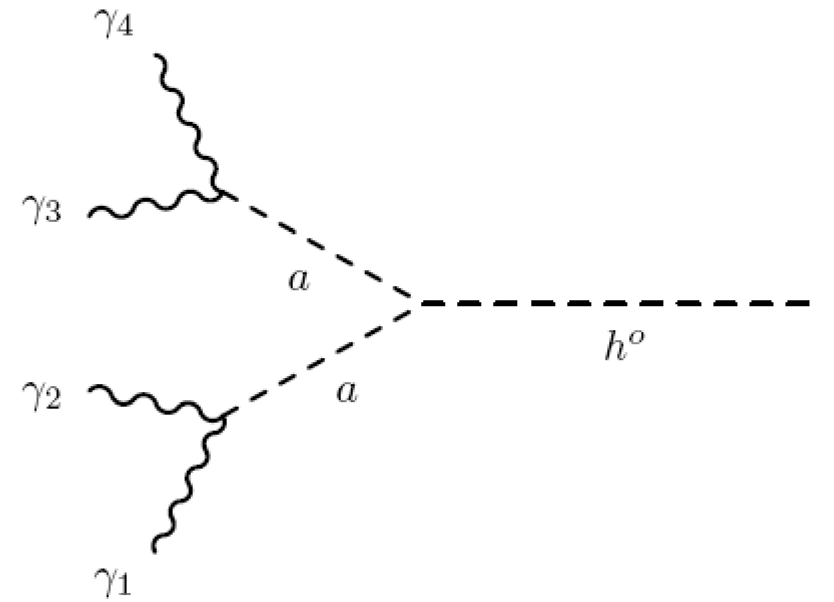
- Allowed for $m_h > 90$-100 GeV
- 4γ very rare, but LHC may have enough statistics

Partonic Analysis: Cuts

SC, Fox, Weiner

Cuts

- $p_T > 20$ GeV
- $\Delta R_{ij} > 0.4$
- $|\eta_i| < 2.5$
- Consistent Match: $|m_{12} - m_{34}| < 5$ GeV



Partonic Analysis: Detector Effects

Follows Atlas TDR

- Jet Fake Rate
- Energy & Angular Smearing (Signal Only)
- 80% photon reconstruction
- All possible combinations binned

Atlas TDR Vol. 1

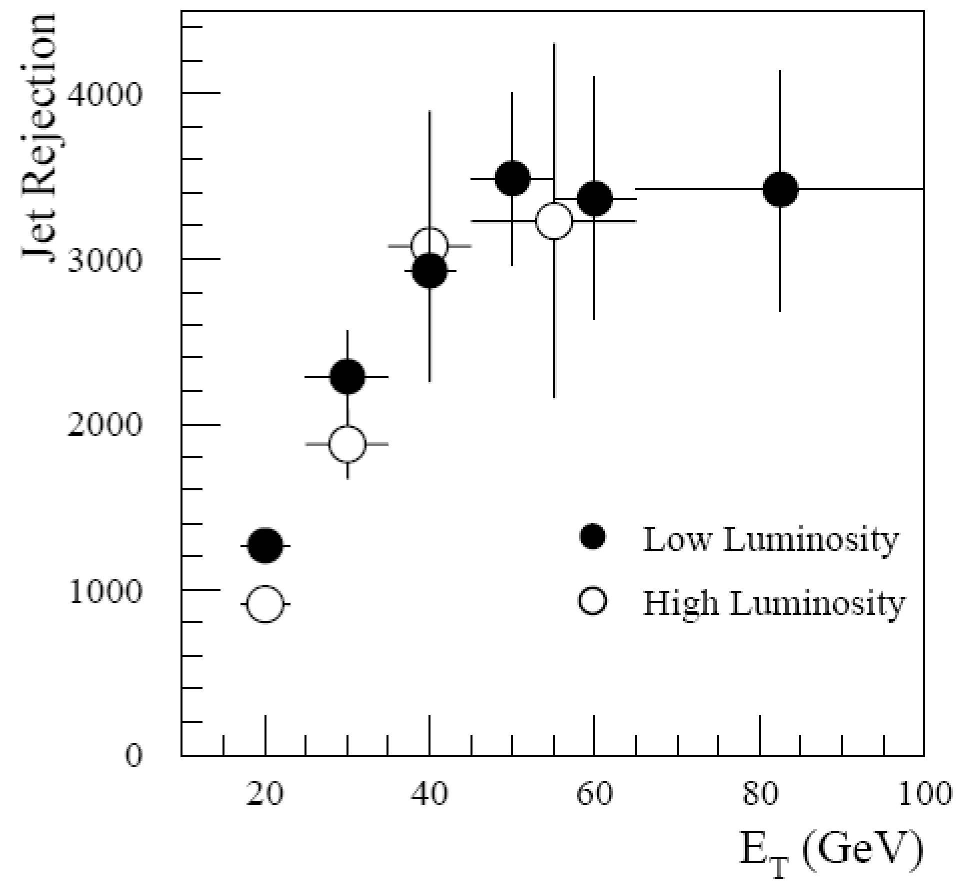
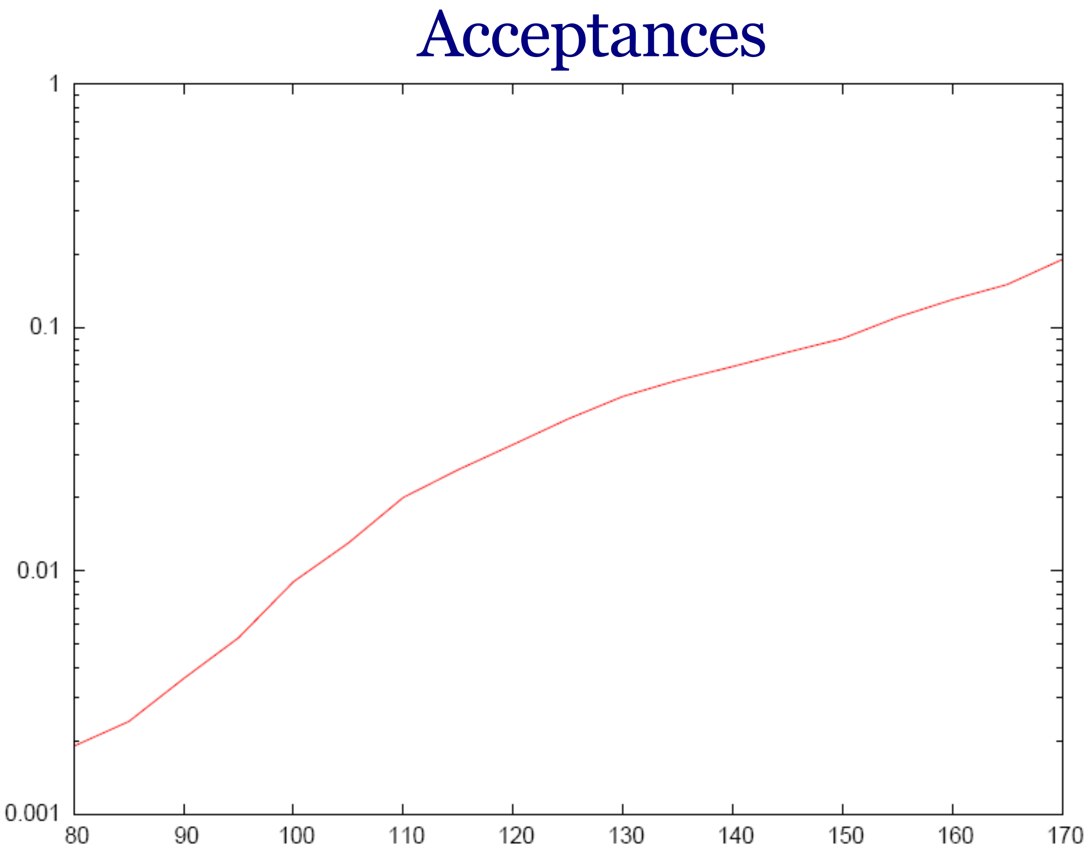


Figure 7-41 Jet rejection after photon selection cuts as a function of jet E_T for low and high luminosity.

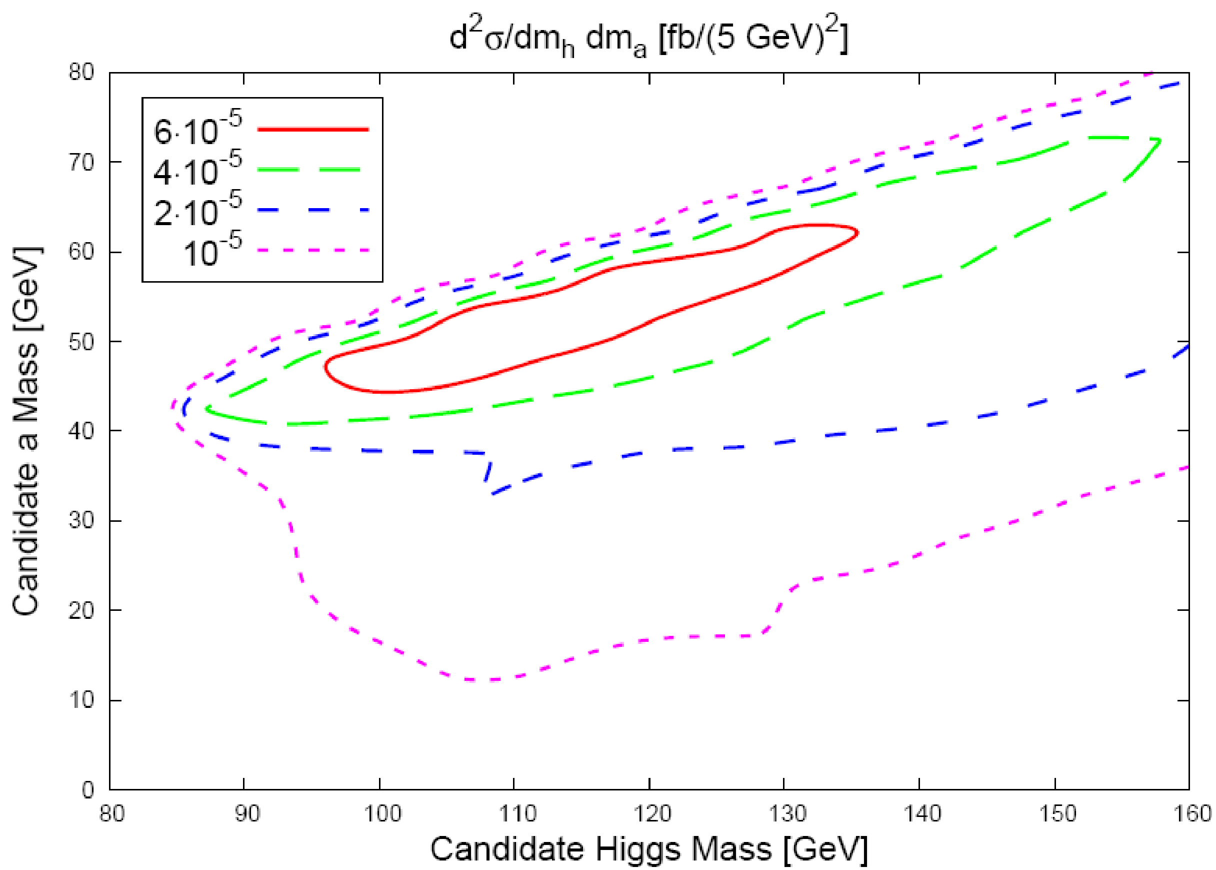
Signal Properties (PYTHIA)

- Acceptances
  - Loosening cut to 15 GeV about 4-10 times larger
- Mass Resolution
  - $\delta m_{h(a)} \sim .1\sqrt{m_{h(a)}/GeV}$ or 1 GeV and .5 GeV for $m_{h(a)}$
- Production
  - NNLO K factor of 2 used



LHC Background (Alpgen)

- 4 photon background, due to real photons and jets faking photons, in 5 GeV mass bins
- Reasonably small, expect <<1 event per bin for 300 fb^{-1}

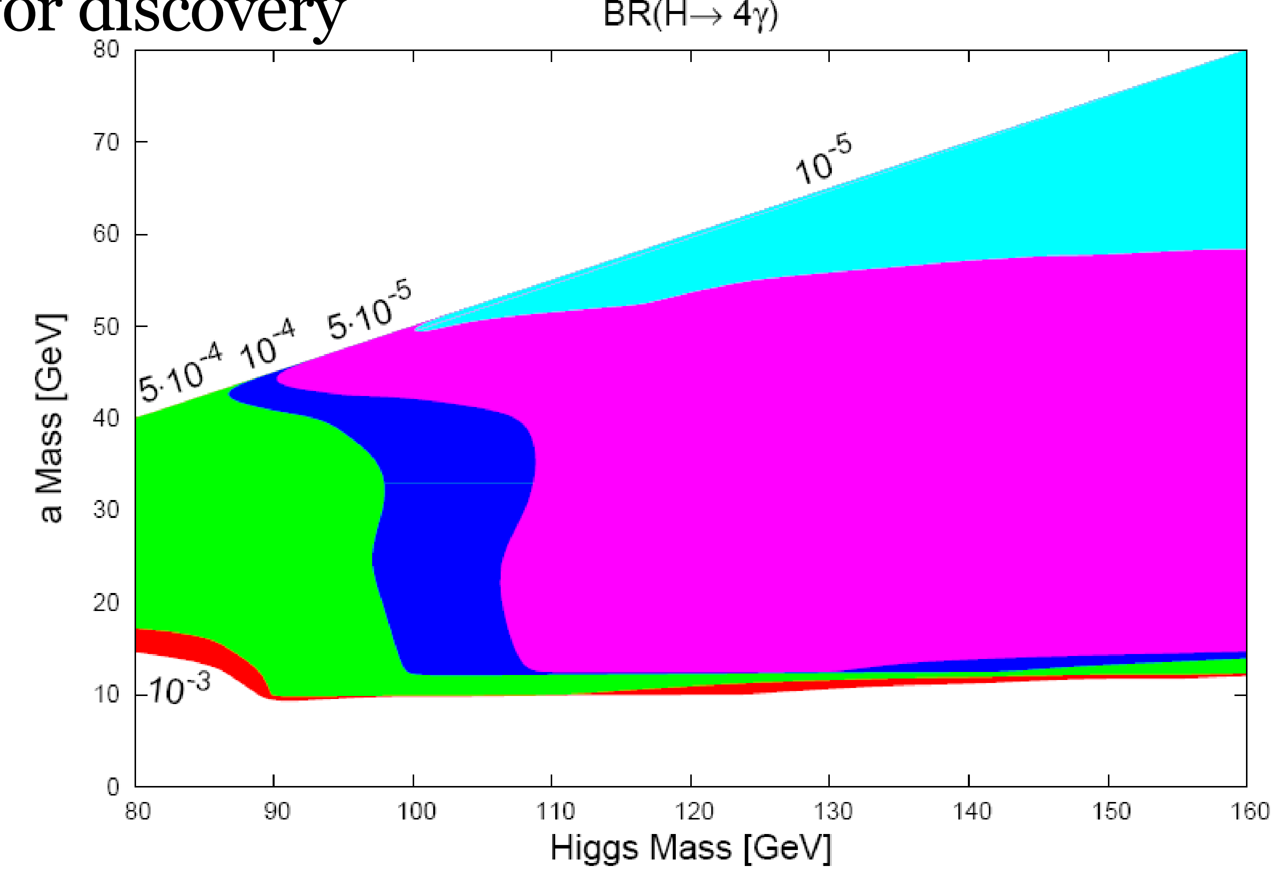


Background is small enough that 5 events in a bin is a 6.3σ fluctuation for 300 fb^{-1}
Less likely to be of consistent m_h and m_a mass

No loop effects!

Discovery at LHC

- Due to small background, 5 signal events are enough (at 300 fb^{-1}) for discovery



10-3 is a rough LEP2 bound

In comparison, Tevatron needs BR > 5x10 -3

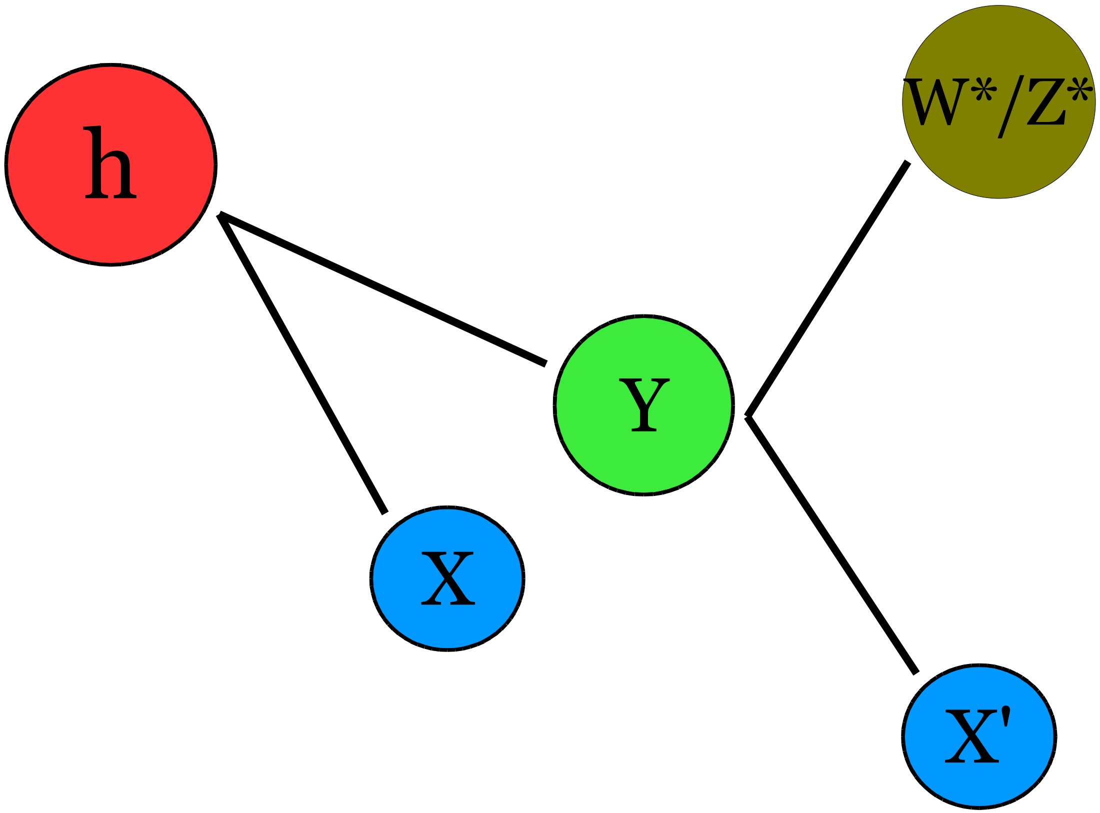
- Acceptance depends on cuts used. Transverse momentum cut on photons is most stringent. More realistic analyses necessary to determine the branching ratio reach.

Acceptance Issues

- Overall p_T cut can be lowered, but…
  - Background level uncertain, as jet fake rate is not simulated to lower values
- Realistic isolation can resolve lower m_a region
- Acceptances highly dependent on overall p_T cut, increasing the trigger level will lose this signal-potential multiphoton trigger?
- Moving to SLHC - can multiple interaction background be controlled (distinguishable vertices?)

One More Possibility

SC, Weiner
work in progress



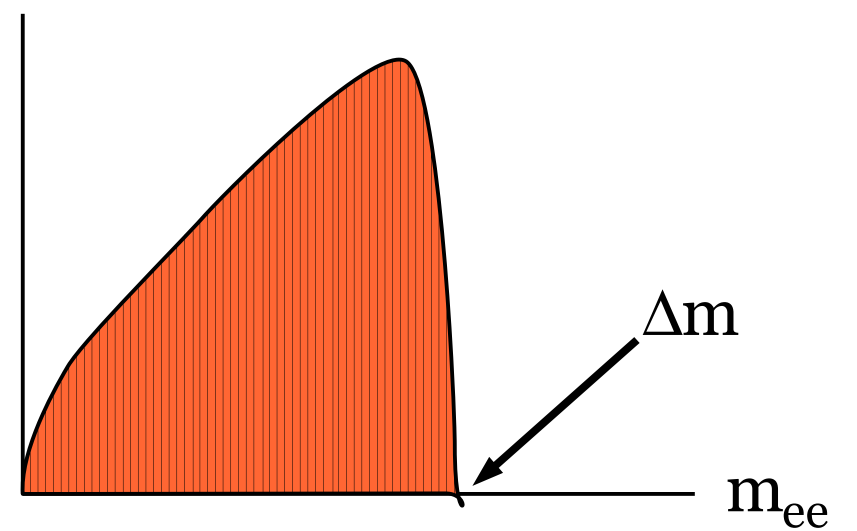
- Neutrinos
  - $h \to \nu_1 \, \nu_2$
    $\quad \quad \quad \quad \llcorner \!\!\to W^* \tau$
  - $h \to \nu_1 \, \nu_2$
    $\quad \quad \quad \quad \llcorner \!\!\to Z^* \nu_1$
- Neutralino & Sneutrino similar to Z* decay

Higgs Decay Search

- Triggering: tau + $\not{E}_T$ (35, 45) GeV, dilepton - 2e or 2μ (15, 10) GeV
- Everything is roughly mh/4 ~ 25 GeV →dileptons
- On the other hand, invisible decay through Z*→ neutrinos (need ~ 200 fb^{-1})
- Visible searches, approach similar to ditau search: Missing Energy + leptons
  - Rates are good – leptonic Z* 6%, leptonic W* 20%
  - Compared to τ_h $\tau_{e,\mu}$ – 2 x .08 x .7 x .3 ~ 3%

Caveats

- Looks like ditau, but …
  - Cannot reconstruct mass via neutrino momenta projection (due to other additional MET objects)
  - No hadronic taus necessarily, no eμ
- Only info on mass differences
- No preliminary analysis
  - Efficiencies?
  - Background?



Conclusions

- New nonstandard Higgs decays can degrade SM searches (an extended situation like h $t\bar{t}$)
- SM searches may take SLHC level luminosities
- New O(1) decays should be searched to attempt to discover Higgs and new physics
- $h \to 4\gamma$ can be searched for at LHC, needs design luminosities, subject to triggering and acceptance issues (also 2g 2γ?)
- $h \to Z^* + \not{E}$ and $h \to W^* \tau + \not{E}$, work to be done

Conclusions (cont.)

- Could be tough
  - Soft activity, trigger and acceptance issues
  - New backgrounds to simulate and control
- Be ready for all possibilities, motivated by:
  - Experimental and theoretical hints
  - Potential inefficiency of SM Higgs searches
  - Discovering new physics