No Higgs Working Group - Summary

Conveners:
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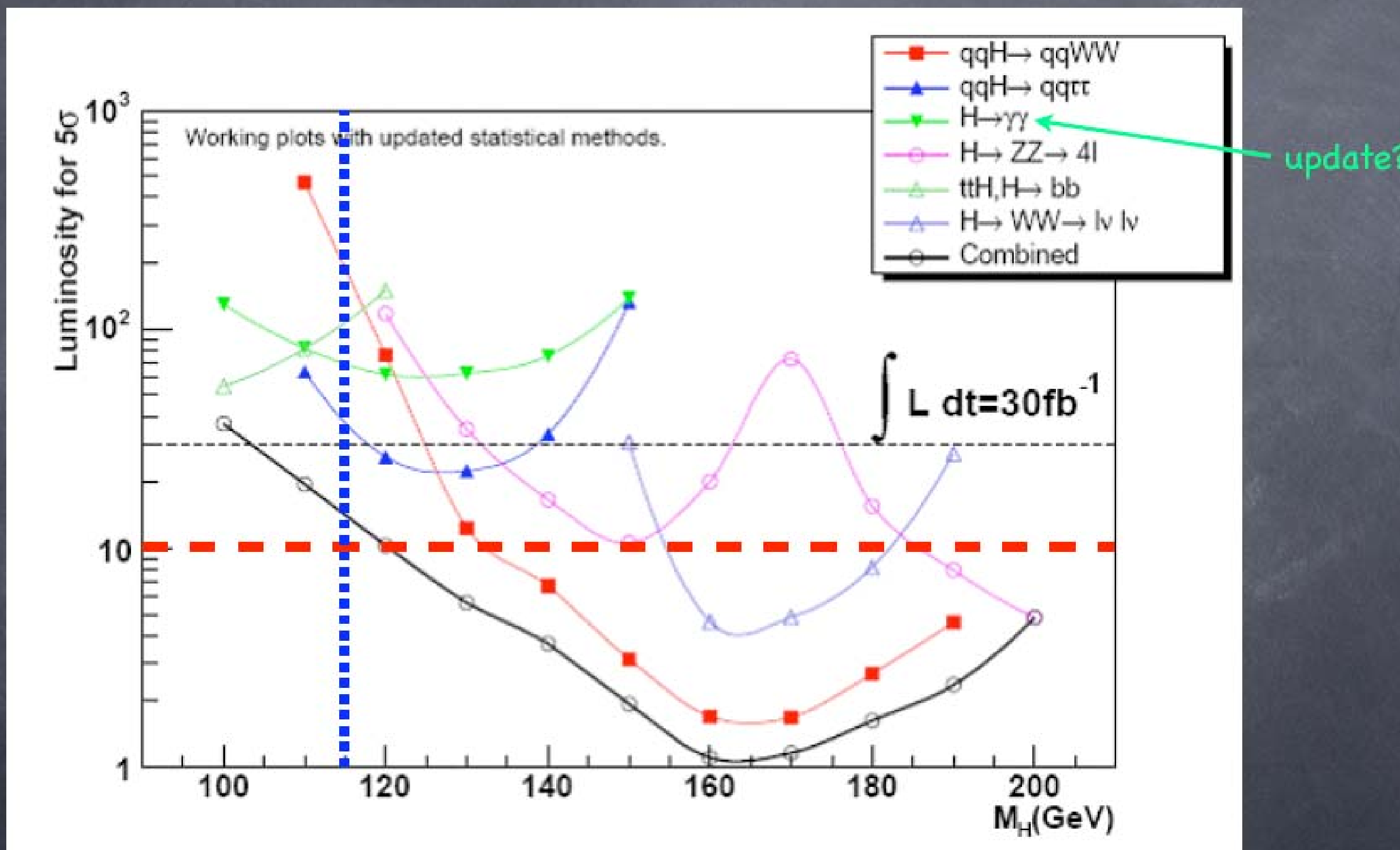
Apr 14, 2007

- Essentially, not seeing the Higgs with 10 fb^{-1} is equivalent to the statement that the Higgs is not SM-like.

The ATLAS Picture



There Truly is No Higgs Boson

- G. Cacciapaglia - No-Higgs scenarios

There is at Least One Higgs Boson, but it Escaped Detection in the First 10 fb^{-1}

- T. Tait - MSSM scenarios
- J. Reuter - Little Higgs
- J. Gunion - Extra/exotic decay channels

No Higgs Models

Phenomenology: Gauge Bosons

[GeV]	0	1	2	3
W	80.4	699	1105	1583
Z	91.2	694	1110	1578
γ (A)	0	718	-	1603
G	0	718	-	1603

Couplings, an example:

Z1 W W	0.034	~ 10% SM
Z1 f_L f_L	(-0.048) T_{3L} + (0.096) Y	~ 10% SM
Z1 t t	(0.46) P_L + (0.44) P_R	~ SM

B(-1/3)	4.5	-	670	943
T(2/3)	172.5	450	622	835
X(5/3)	-	435	-	812

X1) Γ = 6 GeV; W t – 100%

T1) Γ = 1.5 GeV; Z t – 76% W b – 24%

σ (pp -> X1 X1) = 11.3 pb σ (pp -> T1 T1) = 9.3 pb (strong)

- Interesting decay chain X1 -> W^+ t -> W^+ W^+ b
- Final state: 4W+2b-jet
- Studied in Dennis, Unel, Servant, Tseng, hep-ph/0701158: discovery >5σ guaranteed, looked at 1 leptonic decay of Ws.
- Interesting channel: 2 same sign W's decaying leptonically.

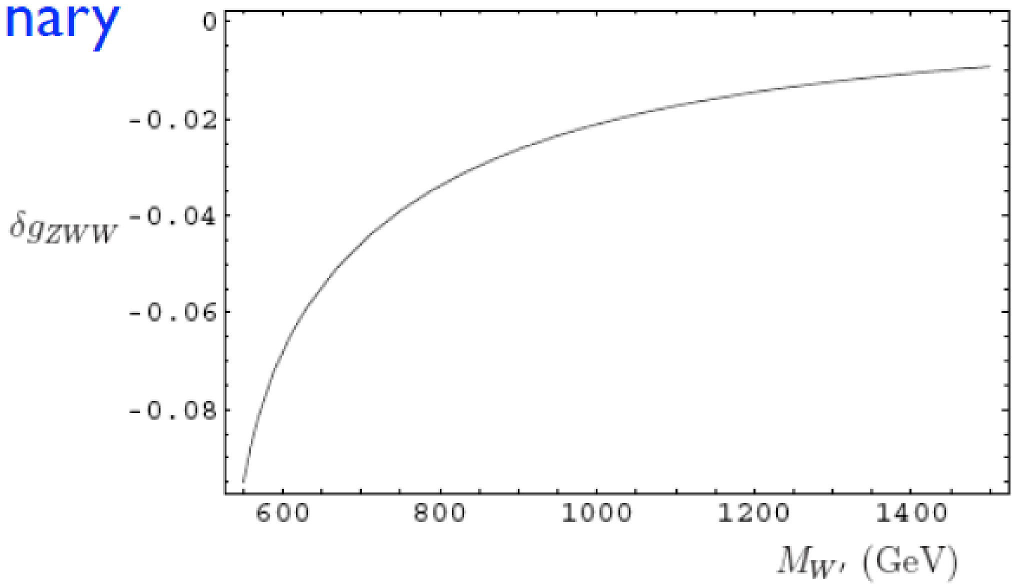
It allows to reconstruct a peak in the 4j+b channel!

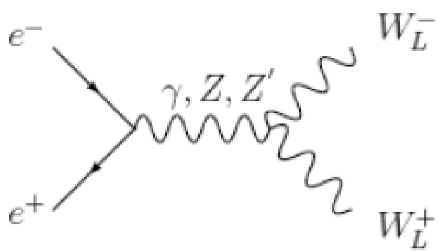
Conclusions and outlook

- EWSB via a strong sector is a viable alternative to the (weakly coupled) Higgs mechanism.
- Extra dimensions are a new handle on the strong sector: perturbative control up to 10 TeV.
- Realistic No-Higgs models are now available.
- Rich phenomenology: >5σ discovery at 10 fb^{-1} for W1, Z1, A1, q1, X1, T1, G1…and more!
- "Indirect" probes: Z t t, W t b (~ 10% deviation) [single top production], WWZ (~2% deviation)
- ILC necessary to study the couplings, and discover other particles (like L1).
- More detailed studies are necessary! (work in progress)

ILC: gzww @ 500 GeV

Preliminary





$$\delta g_{ZWW} = \frac{g_{LeZ}\, g_{ZWW}}{g^{sm}_{LeZ}\, g^{sm}_{ZWW}} + \frac{g_{LeZ'}\, g_{Z'WW}}{g^{sm}_{LeZ}\, g^{sm}_{ZWW}} \left(\frac{s - M_Z^2}{s - M_{Z'}^2} \right) - 1$$

ILC sensitivity ~4 x 10^{-4} with 500 fb^{-1}

Case for 500 GeV ILC when There Truly is no Higgs Boson

- Indirect probes of Ztt, Wtb, ZWW couplings at the ILC with Ecm=500 GeV would be valuable but ..
- Discovery of resonances in 500 – 1000 GeV range at LHC in first 10 fb^{-1} would create demand for a rapid upgrade in ILC energy from Ecm=500 GeV.

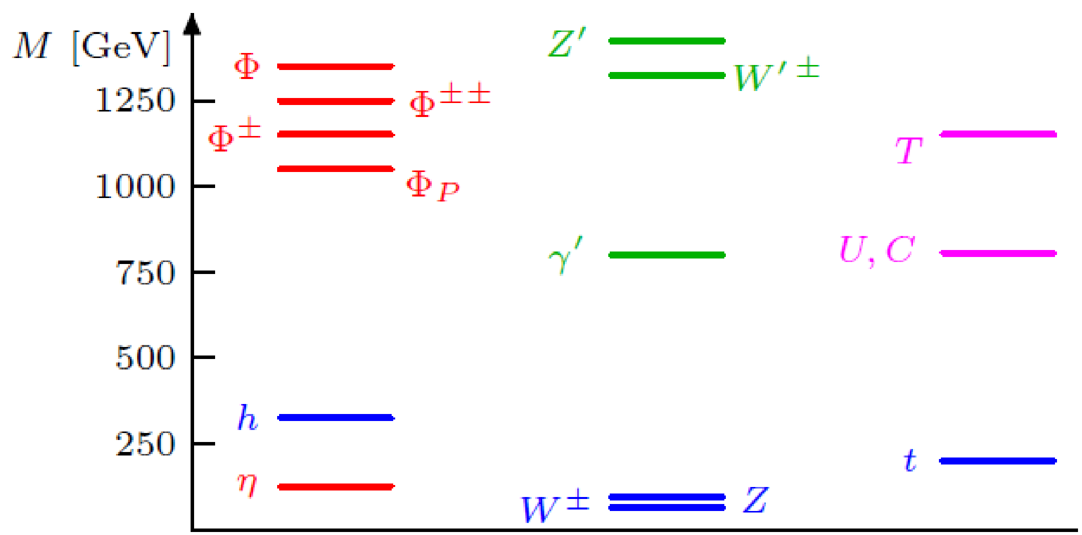
Little Higgs Models

Properties of Little-Higgs models

- Extended global symmetry
- Specific functional form of the potential
- Extended gauge symmetry:
  $\gamma', Z', W'^{\pm}$
- New heavy fermions: T, but also $U, C, \ldots$

Example: Littlest Higgs

Arkani-Hamed/Cohen/Katz/Nelson, 2002



No (early) Higgs signal in Little Higgs model

- How to miss a Higgs signal in the early phase of LHC in Little Higgs models?
  - There is always a Higgs boson in LHM
  - Very light Higgs needs time to be discovered
  - Heavier Higgs
    maybe unusual decay modes (almost always beaten by VV)
- LHM usually have rather heavy Higgs
  - will be discovered very soon (cf. Kyle Cranmer's talk)

    if $M_H \lesssim 550\,\text{GeV}$
    will be very difficult for larger Higgs masses
  - Assumption: some info about Z', W' or heavy top excluding the SM
  - Search for light Higgs states (2HDM, or single heavy Higgs)
- Confusion with a Higgs-like signal from a different particle possible with other (pseudo-)scalars in the game

Outlook/Discussion

- Higgs is always present in Little Higgs models
- Higgs is generically heavy in LHM; will be captured by VV mode
- Higgs might be confused with other members from its Goldstone multiplet, especially with light pseudo-axions
- Three possible scenarios interesting for ILC:
  - very heavy and broad Higgs, (very) light pseudoaxion; both missed at early stage of LHC
  - heavy Higgs detected in $H \to ZZ \to 4\ell$; light partner missing
  - inverted hierarchy: Higgs light, pseudoaxion heavy; both are missed at early stage of LHC
- Possible degeneracies between Higgs/pseudoaxion
- Cross references from heavy quark and Z', W' discoveries
- LHM mimicking Higgsless models?
- Importance of invisible decays?

Case for 500 GeV ILC when Higgs Boson of Little Higgs Model is not Seen in First 10 fb^{-1}

- Situation will be similar to case that there truly is no Higgs boson. Resonances above 500 GeV will have been seen at LHC. (Note: it probably is not possible to distinguish between no-Higgs and little Higgs models after 10 fb^{-1} if no Higgs boson has been seen.)
- Indirect probes of Ztt, Wtb, ZWW couplings at the ILC with Ecm=500 GeV will be valuable. The ILC at Ecm=500 GeV would be very effective in discovering any light Higgs bosons in the Little Higgs Model.
- Discovery of resonances in 500 – 1000 GeV range at LHC would create demand for a rapid upgrade in ILC energy from Ecm=500 GeV, although this demand would be tempered by any discovery of a light Higgs boson in higher luminosity LHC running.
- We need to understand better the circumstances under which a Higgs boson will not be seen by the LHC in 10 fb^{-1} in the little Higgs scenario.

SUSY Models

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.

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.

Additional Singlets

Each new singlet leads to a new scalar, pseudoscalar and neutralino. The new scalar and pseudoscalar will in general mix with the existing neutral scalars h^0, H^0 A^0

$$\Gamma(h_i^0 \to h_j^0 h_j^0) = \frac{g^2 m_{h_i^0}^3}{128\pi m_W^2} \sim 0.17 \text{ GeV} \left(\frac{m_{h_i^0}}{100 \text{ GeV}}\right)^3 \quad vs.$$

$$\Gamma(h_i^0 \to b\bar{b}) \sim 0.003 \text{ GeV} \left(\frac{m_{h_i^0}}{100 \text{ GeV}}\right) \quad and$$

$$\Gamma(h_i^0 \to ZZ) = \frac{1}{2}\Gamma(h_i^0 \to WW) = \frac{g^2 m_{h_i^0}^3}{128\pi m_W^2} .$$

Summary: Higgs to Higgs decays can be dominant when WW, ZZ channels are not open and can still be substantial even when they are.

Conclusions

My bias:
The combination of:

1. the precision electroweak preference for a SM-like Higgs with $m_h \sim 100~\mathrm{GeV}$,
2. the old LEP excess (at reduced rate) at this mass in the $b\overline{b}$ channel,
3. the fact that supersymmetric models evolved to the GUT scale have minimal fine-tuning for such a mass,

all combine to suggest that the LHC may have to find the Higgs boson by looking for $h \to pp$ where p then decays in some way that evades the LEP $m_h > 114~\mathrm{GeV}$ bound.

There are many possibilities for p and how it decays with $p =$ a pseudoscalar and $p =$ a neutralino or other light SUSY particle being prominent on the list.

p decays can be constructed in both cases to avoid LEP limits and make LHC discovery very difficult.

Case for 500 GeV ILC when SUSY Higgs Bosons are Present but not Seen by LHC in First 10 fb^{-1}

- If phenomena consistent with SUSY has been seen and there is evidence for light SUSY particles (charginos, neutralinos) in cascade decays of gluinos and squarks, then we may have in this case the best motivation for a 500 GeV ILC: study the light gauginos and find the lightest Higgs boson with mass < 130 GeV.
- If phenomena consistent with SUSY has been seen but there is no evidence for light SUSY particles then the 500 GeV ILC might be a harder sell. How far can we push the need to search for the lightest Higgs boson with mass < 130 GeV?
- If SUSY Higgs bosons are present but haven't been seen, and gluinos and squarks are too massive to have been seen at LHC in first 10 fb^{-1} , then we are in a tough situation because the LHC hasn't seen anything in the first 10 $fb^{-1.}$ It is to the advantage of the ILC to start preparations now for the detection of Higgs decays to scalars at the LHC, and to improve LHC searches for objects such as light stop squarks (which may be present even if gluinos and light flavor squarks are very massive).