DETERMINING PARAMETERS OF THE LITTLEST HIGGS MODEL AT THE ILC

OUTLINE:

1.) THE LITTLEST HIGGS MODEL
- Introduction and Parameters of the model
- Spectrum + Couplings

2.) ANALYSIS
- $e^+e^- \to f\bar{f}$
  - LEP II constraints
  - ILC search reach
  - ILC Parameter Fits
- $e^+e^- \to Zh$
  - ILC search reach

3.) CONCLUSIONS

THE LITTLEST HIGGS (LH) MODEL

- Arkani-Hamed, et. al. hep-ph/0206021

LIKE OTHER LITTLE HIGGS MODELS:

- Based on a spontaneously broken non-linear σ model
- UV cut-off ~ 10 TeV
- Higgs is pseudo-Goldstone boson of global symmetry
- Higgs mass quadratic divergences come in only at two loops*

FOR THE LITTLEST HIGGS:

$4\pi f$

*This protects m_h^2 from one-loop div.

$[SU(2) \times U(1)]^2 \subset SU(5)$ Global Symmetry

Gauged

$\downarrow$ vev ~ f $\qquad \downarrow$

$[SU(2)_L \times U(1)_Y] \subset SO(5)$

$\downarrow$ $v \sim f/4\pi$

EM

The Littlest Higgs Model Contd.

Parameters

- f - since $v \sim f/4\pi$ and UV cutoff $\sim 4\pi f$, then $f \sim$ few TeV
  - If $f \gtrsim 10$ TeV it no longer addresses naturalness

- s, s' - mixing angles for mass e'states after $SU(5) \to SO(5)$

$$W = sW_1 + cW_2 \quad W' = -cW_1 + sW_2$$

$$B = s'B_1 + c'B_2 \quad B' = -c'B_1 + s'B_2$$

  - functions of coupling constants of $[SU(2) \times U(1)]^2$

$$s = \frac{g_2}{\sqrt{g_1^2 + g_2^2}} \quad , \quad s' = \frac{g_2'}{\sqrt{g_1'^2 + g_2'^2}}$$

- The model has an interesting top sector with some more params. For our analysis ($e^+e^- \to f\bar{f}$ and $e^+e^- \to Zh$), at tree level, these three ar only relevant params.

NEUTRAL GAUGE BOSON SPECTRUM

($\exists\ W_H^{\pm}$, but not important for our analysis)

Then after EWSB, mass e'states:

$A_L \rightarrow$ massless (phew!)

$Z_L \rightarrow$ tiny corrections

$$M_{Z_L}^2 = M_{Z_{SM}}^2 \left[1 + \mathcal{O}(v^2/f^2) \right]$$

$A_H \rightarrow$ heavy "photon"

$$m_{A_H}^2 = M_{Z_{SM}}^2 S_w^2 \left(\frac{f^2}{5 s'^2 c'^2 v^2} - 1 + \frac{x_H C_w^2}{4 s^2 c^2 S_w^2} \right)$$

$Z_H \rightarrow$ heavy "Z"

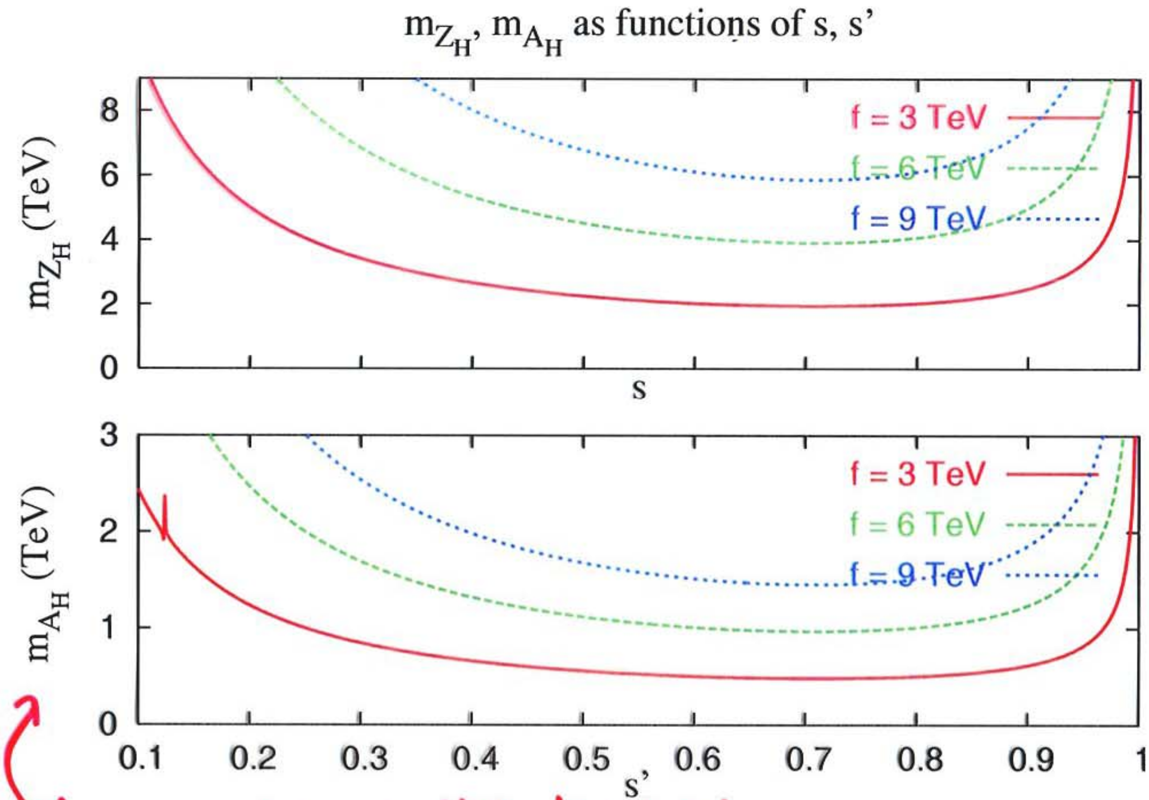
$$m_{Z_H}^2 = M_{W_{SM}}^2 \left(\frac{f^2}{s^2 c^2 v^2} - 1 - \frac{x_H S_w^2}{4 s'^2 c'^2 C_w^2} \right)$$

Dominant term - s vs. s' dependence

Note:

- m_Z^2 corrections $\sim .01$ shift ρ
  - Hewett, et. al. hep-ph/0211218
- x_H is $\mathcal{O}(1)$ mixing parameter, fn. of s, s'
  - Han, et. al. hep-ph/0301040

· Masses of Neutral Gauge Bosons



A_H gets quite light!

$m_{A_H} \lesssim 1$ TeV for $f = 3$ TeV.

EXISTING CONSTRAINTS

- Strong constraints from Tevatron and precision EW ($f \gtrsim 4$ TeV at best)
  - Hewett, et. al. hep-ph/0211218
  - Csaki, et. al. hep-ph/0211124
- Contributions from light A_H dominate in generic cases
- Many models have been invented that decouple A_H in one way or another
  - e.g. Csaki, et. al. hep-ph/0303236
    Gregoire, et. al. hep-ph/0305275
    Kilic + Mahbubani hep-ph/0312053
- We work with Littlest Higgs model b/c it is well studied.

↳ To evade A_H problems, we can:

We do both –
1) Choose parameters ($s' = \sqrt{3/5}$) for which A_H decouples
2) Artificially send $m_{A_H} \to \infty$
   - This is not theoretically consistent, but gives a general idea of behavior of models that evade A_H problem

COUPLINGS IN LITTLEST HIGGS

- Heavy particle couplings

A_H sector
s'-dep.

$$g_{V/A}(f\bar{f}A_H) \sim \frac{g'}{s'c'}\left(\frac{c'^2}{2} - \frac{1}{5}\right)$$

↖ vanish at $s' = \sqrt{3/5}$

Z_H sector
s-dep.

$$g_{V/A}(f\bar{f}Z_H) \sim \frac{gc}{s}$$

- 'SM' particle couplings shifted

$$\Delta g_{V/A}(f\bar{f}Z_L) \sim v^2/f^2$$ (both s and s' dependent)

- Note for $e^+e^-Z_L$:

$|\Delta g_V^e| \sim |\Delta g_A^e|$, while
$|g_V^e| << |g_A^e|$.

But since $\sigma \propto g_V^2 + g_A^2$,
while $A_{LR} \propto g_V g_A$
need A_{LR} to be sensitive to $\Delta g_{V/A}$

↳ Thus in models with A_H decoupled, only sensitive to s' if can measure A_{LR}

→ Importance of beam polarization

ANALYSIS: $e^+e^- \to f\bar{f}$

★ $\int \mathcal{L} = 500\ fb^{-1}$ ★

- Looked at

  $e^+e^- \to f\bar{f}$ at

  LEP II (constraints)

  and LC★ (search reach, param fits)

- Final states + efficiencies:

  $\tau^+\tau^-$, $\mu^+\mu^-$, e^+e^- (95%), ← For LC

  $b\bar{b}$ (60%), $c\bar{c}$ (35%).

- Observables:

  LEP II: Normalized, binned angular dist. and total σ

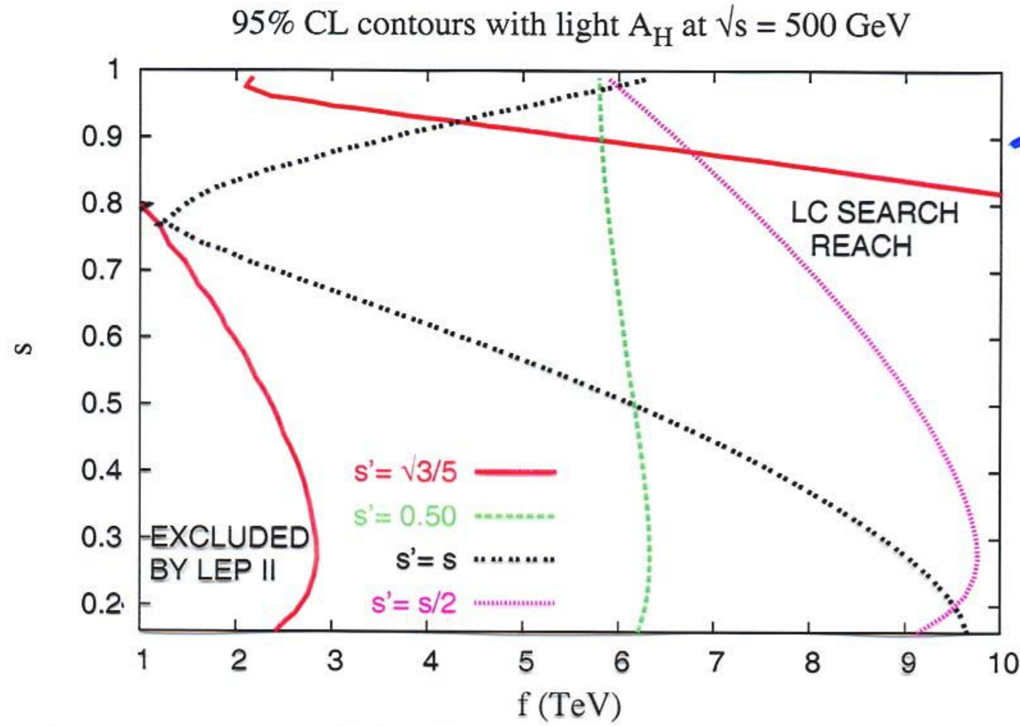
  LC: same as above + binned A_{LR}

- Used $$\chi^2 = \sum_i \left(\frac{O^i_{LH} - O^i_{SM}}{\delta O^i} \right)^2$$

- 95% CL Regions correspond to

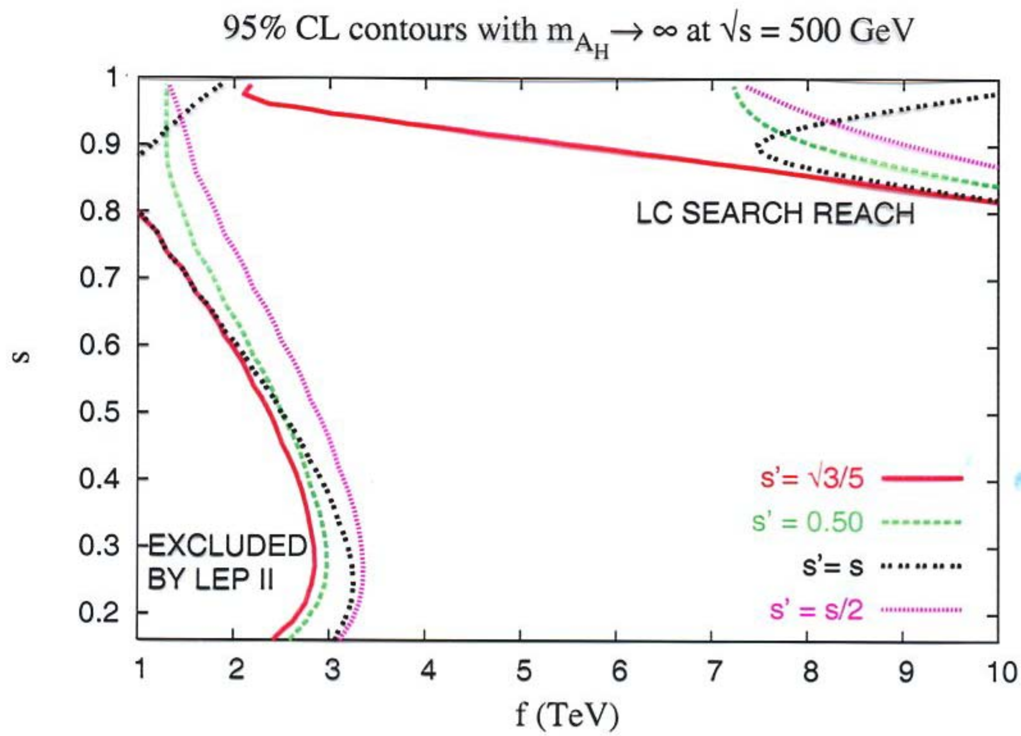
  $\chi^2 > 5.88$ (2 DOF) always fix 1 comb. of 3 params.

LEP II Constraints and ILC search reach using $e^+e^- \to f\bar{f}$



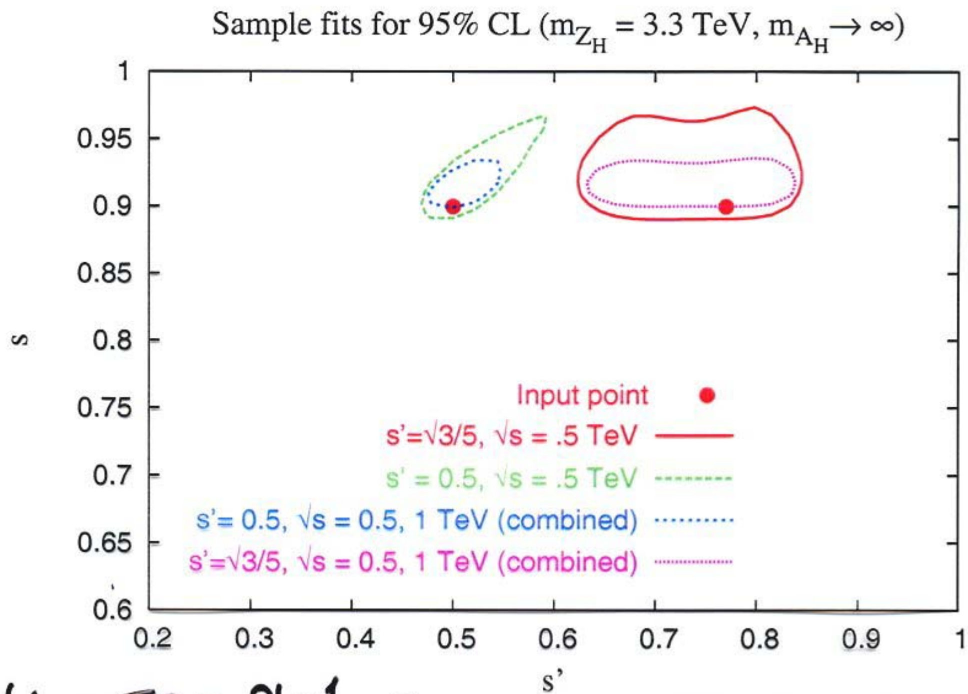
→ other LC search reaches cover whole param. space

$\int \mathcal{L} dt = 500 \text{ fb}^{-1}$



Parameter fits at ILC using $e^+e^- \to f\bar{f}$ (fixed m_{Z_H})

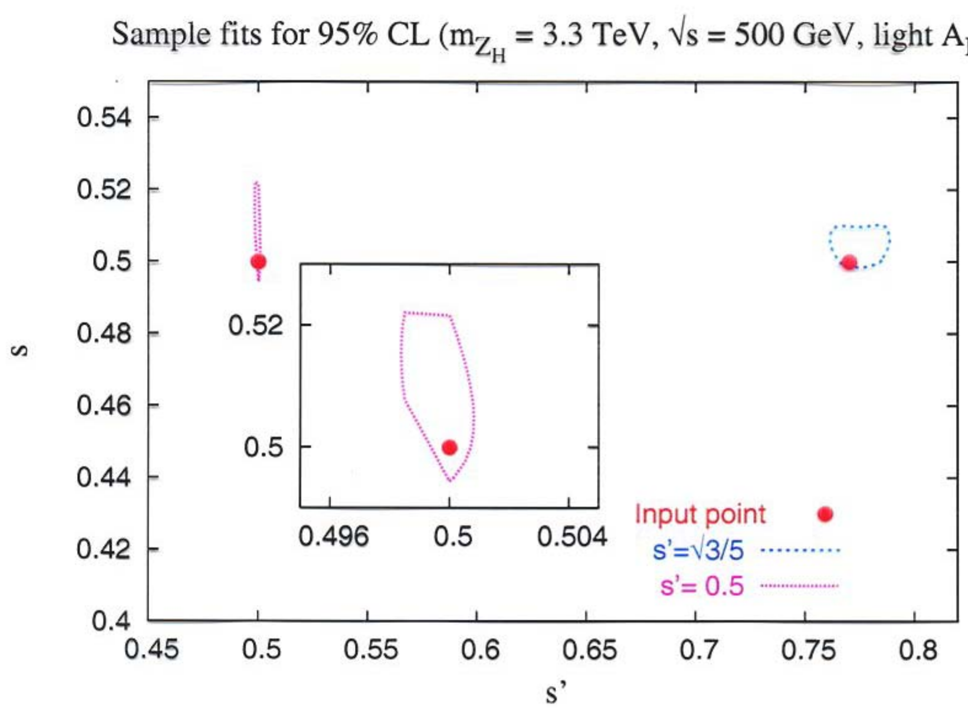
$m_{A_H} \to \infty$



Combined 500 GeV and 1 TeV data set improves fit

$\int \mathcal{L} dt = 500\ fb^{-1}$ for each $\sqrt{s} = 500$ GeV and 1 TeV

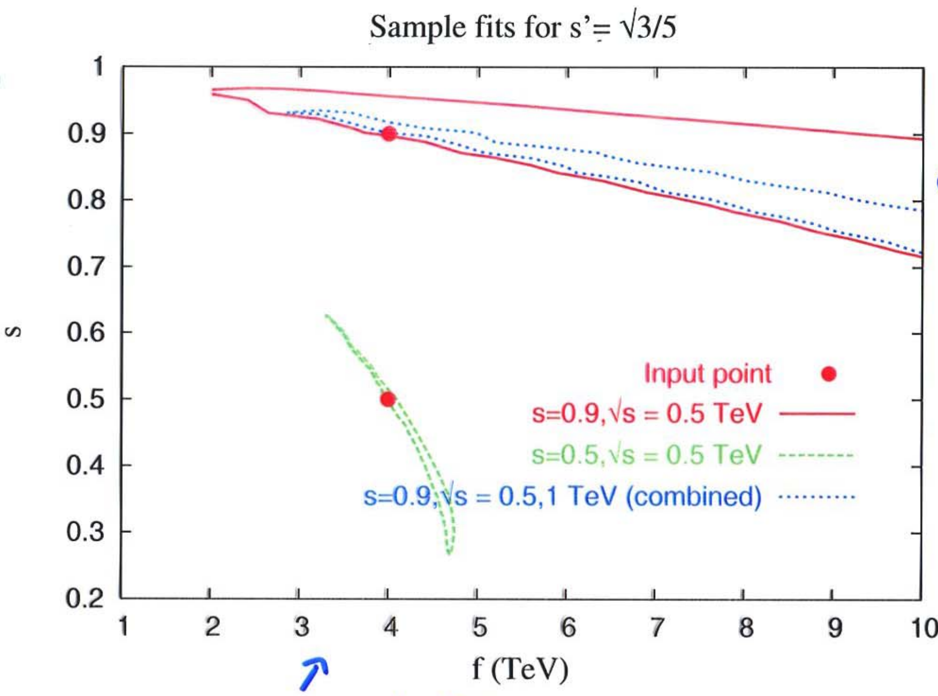
light m_{A_H}



Fit much better with light A_H

Parameter fit (fixed s') at ILC using $e^+e^- \to f\bar{f}$.

• This could happen if LHC doesn't determine masses



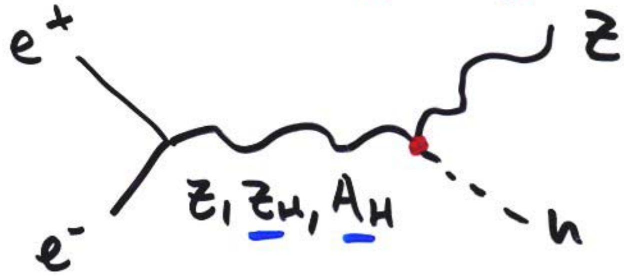
It's possible that fit region doesn't close

Not a great fit even if it closes

$\int \mathcal{L}\, dt = 500\ fb^{-1}$

ANALYSIS: $e^+e^- \to Zh$

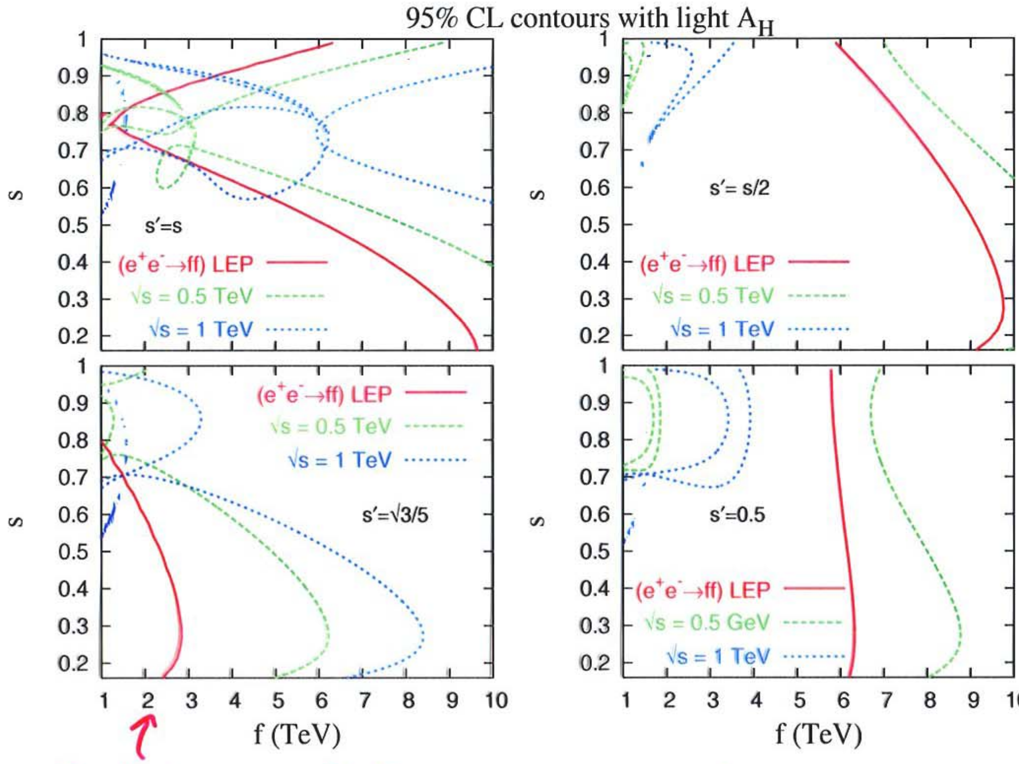
- IMPORTANT: Hallmark of Little Higgs models is coupling of heavy gauge bosons to Zh ⇒ we should measure this coupling to prove we have Little(st) Higgs



- Deviations from SM in σ_{Zh}:
  - Deviations of ZZh coupling
    - $\mathcal{O}(v^2/f^2)$, both s and s' dep.
  - Presence of Z_H, A_H in s-channel
    - $Z_H Z h$ coupling $\propto c^2 - s^2$, only s-dep. (vanishes at $s = 1/\sqrt{2}$)
    - $A_H Z h$ coupling $\propto c'^2 - s'^2$, only s'-dep. (vanishes at $s' = 1/\sqrt{2}$)
- We use total σ as observable
- We assume that at ILC at $\sqrt{s} = 500$ GeV, $\int \mathcal{L} dt = 500\ \text{fb}^{-1}$, we will obtain $\frac{\delta\sigma_{Zh}}{\sigma_{Zh}} \simeq 1.5\%$ (TESLA TDR)

ILC Search Reach using $e^+e^- \to Zh$ with light A_H

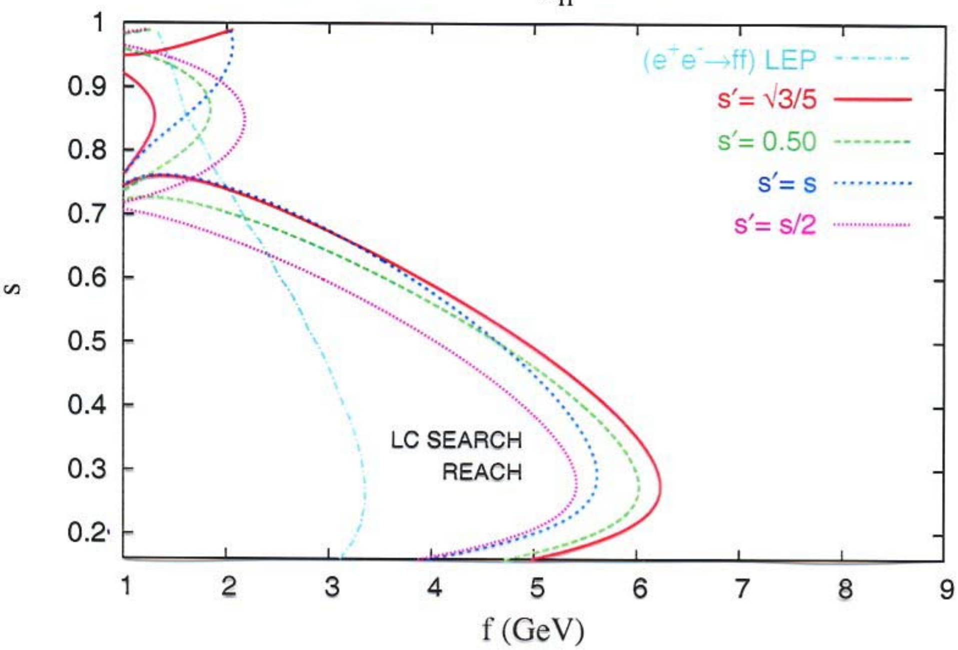
$\int \mathcal{L} dt = 500\ fb^{-1}$ for each 500 GeV and 1 TeV



Red is LEP II constraint from $e^+e^- \to f\bar{f}$

ILC Search reach using $e^+e^- \to Zh$ with $m_{A_H} \to \infty$

95% CL contours with $m_{A_H} \to \infty$ at $\sqrt{s} = 500$ GeV

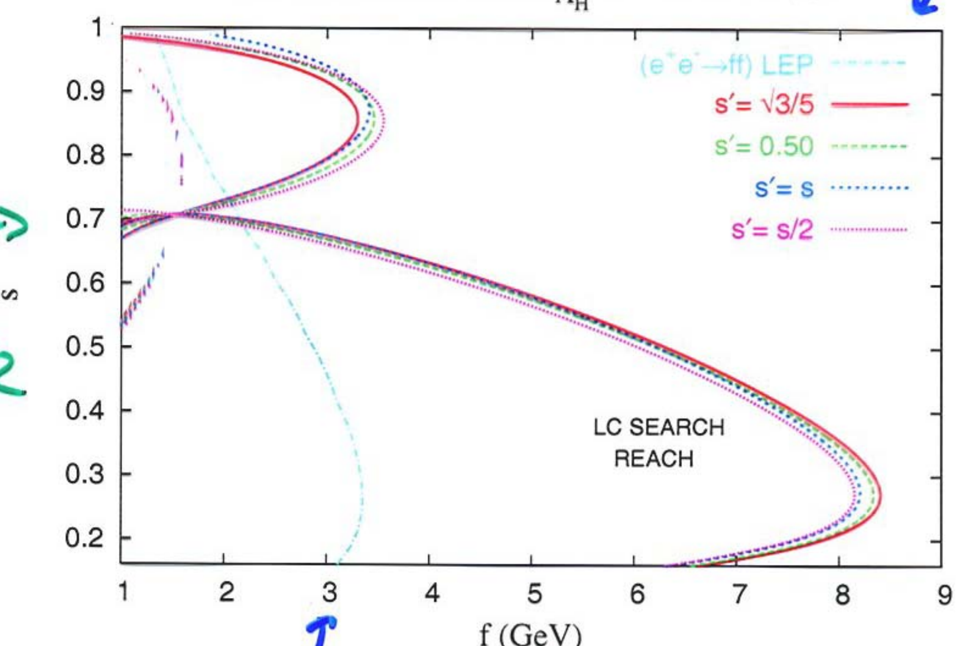


$\int \mathcal{L} dt = 500\ fb^{-1}$

A lot of param space not covered (maybe other obs. would help)

95% CL contours with $m_{A_H} \to \infty$ at $\sqrt{s} = 1$ TeV

$Z_L Z_H h$ coupling → vanishes at $s = \sqrt{2}/2$



$\int \mathcal{L} dt = 500\ fb^{-1}$

↑ Blue is LEP II constraint from $e^+e^- \to f\bar{f}$

CONCLUSIONS:

FOR THE LITTLEST HIGGS MODEL:

- The ILC covers most of the interesting parameter space
- The ILC provides accurate determination of parameters (helpful if we have f from LHC)
- $e^+e^- \to Z h$ gives, in some regions of parameter space, confirmation of the hallmark feature of Little Higgs.