Little Higgs models and LC

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Introduction

- The hierarchy problem
  - SUSY : a leading candidate

- Alternative approach?
  - Extra-D?
  - Little Higgs models: Arkani-Hamed etal. (2002)

Little Higgs models

- at certain high E. scale, a theory with
  - global symmetry $\mathcal{G}$
  - gauge symmetry $G_1 \times G_2 (\supset G_{SM})$
- both symmetries are broken at $\Lambda_s \sim 4\pi f$: G_{SM}
  - global sym. : (pseudo) goldstone bosons
  - gauge sym. : extra heavy gauge bosons
- EW symmetry breaking
  - 1-loop effective potential (a la Coleman-Weinberg)
- needs extra vector-like fermions (to cancel quad.div)

consequences

- quad. div. of Higgs: from 2-loop
  - relatively small corrections stabilize the Higgs mass up to the scale Λ
- some extra fields at TeV scale
  - heavy gauge bosons
  - extra (vector-like) fermions

Littlest Higgs model

- simplest version: Arkani-Hamed etal, (2002)
  - global symmetry: SU(5)
  - gauge symmetry: $[SU(2) \times U(1)]_1 \times [SU(2) \times U(1)]_2$
- consider sym.breaking SU(5) → SO(5)
  - gauge sym. is broken simultaneously → G_{SM}
  - # of Goldstones: 24-10=14

$$\mathbf{1},\ \mathbf{3}_0 : \text{ massive } (W'\&Z')$$
$$\mathbf{2}_{\pm 1/2},\ \mathbf{3}_{\pm 1} : \text{ massless}$$

- non-linear sigma-model

decay constant

$f \sim \Lambda/4\pi$

$$\mathcal{L} = \frac{1}{2}\frac{f^2}{4}\mathrm{Tr}|D_\mu \Sigma|^2$$

covariant derivative for $[SU(2)xU(1)]^2$

$$\Sigma = e^{i\frac{\pi}{f}}\Sigma_o e^{i\frac{\pi}{f}}$$

extra gauge bosons

$$\begin{pmatrix} W \\ W' \end{pmatrix} = \begin{pmatrix} s & c \\ -c & s \end{pmatrix} \begin{pmatrix} W_1 \\ W_2 \end{pmatrix}$$

$W, B \cdots$ SM gauge bosons (massless)

$$\begin{pmatrix} B \\ B' \end{pmatrix} = \begin{pmatrix} s' & c' \\ -c' & s' \end{pmatrix} \begin{pmatrix} B_1 \\ B_2 \end{pmatrix}$$

$W', B' \cdots$ extra gauge bosons (massive)

$s \equiv \sin\theta, \quad s' \equiv \sin\theta'$

after EWSB …

$$\begin{pmatrix} W_L \\ W_H \end{pmatrix} = U_W \begin{pmatrix} W \\ W' \end{pmatrix} \qquad \begin{pmatrix} A_L \\ Z_L \\ A_H \\ Z_H \end{pmatrix} = U_N \begin{pmatrix} W^3 \\ B \\ W'^3 \\ B' \end{pmatrix}$$

$$\begin{aligned} m^2_{A_L} &= 0 \\ m^2_{Z_L} &= m^2_Z(1 + O(v^2/f^2)) \\ m^2_{W_L} &= m^2_W(1 + O(v^2/f^2)) \end{aligned} \qquad \begin{aligned} m^2_{A_H} &\sim O(f^2) \\ m^2_{Z_H} &\sim O(f^2) \\ m^2_{W_H} &\sim O(f^2) \end{aligned}$$

the gauge sector is fixed by: $f, \tan\theta, \tan\theta'$

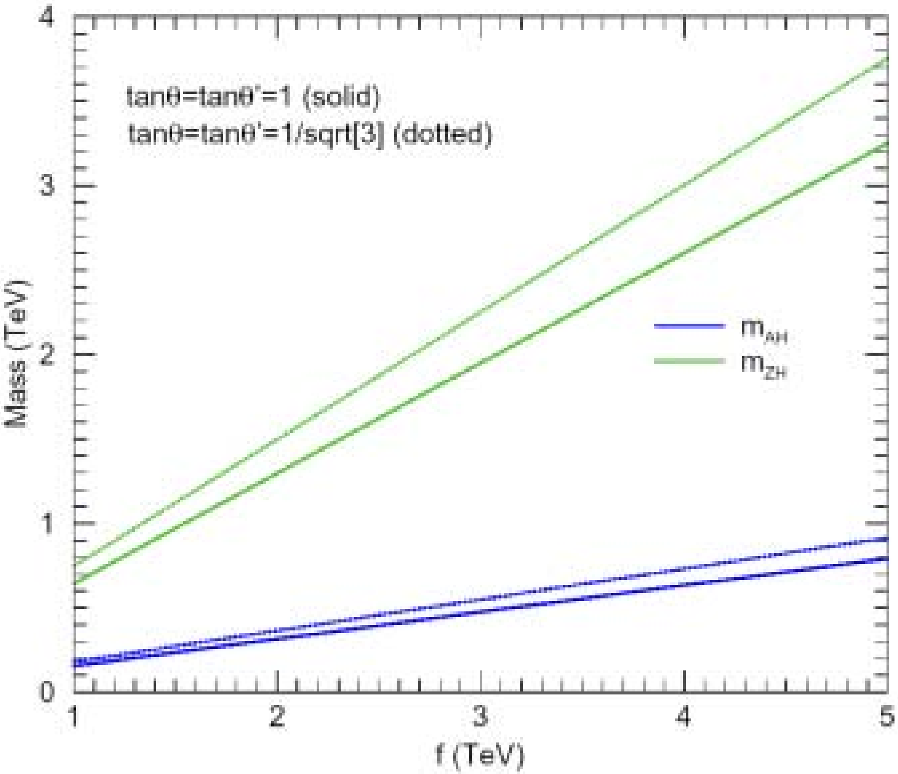
constraints on LH model

- Hadron collider: $p\bar{p} \rightarrow A_H X$
  - Han etal (2003), Hewett etal (2002)

$$f \geq 3.5 - 4\text{TeV}$$

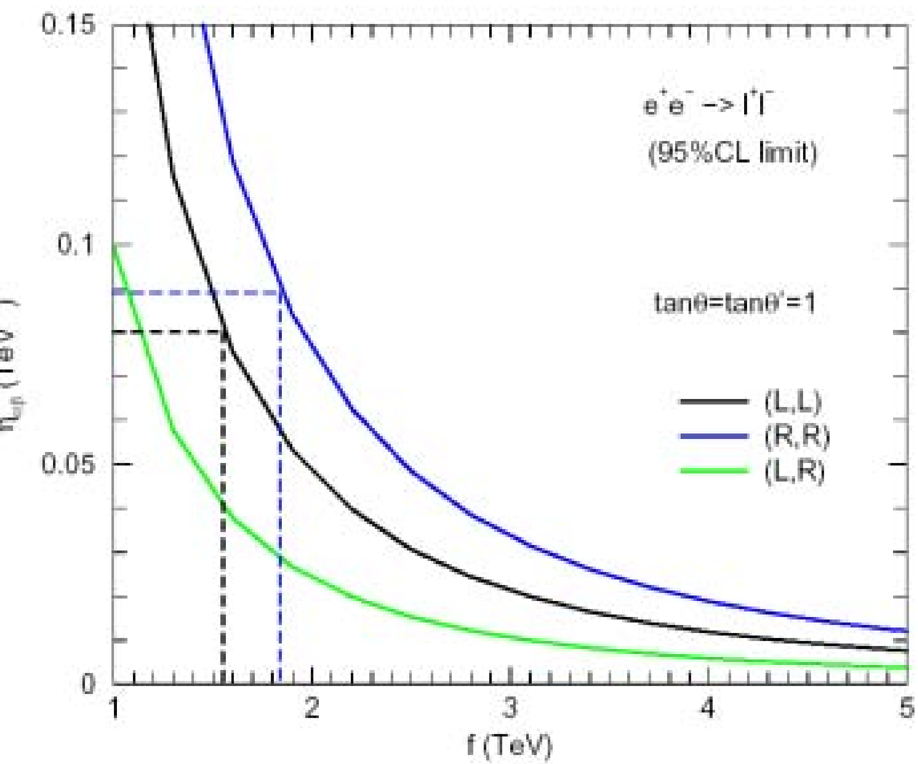
- e^+e^- collider?
  - contact interaction at LEP2
  - $e^+e^- \rightarrow \mu^+\mu^-$ at LC

Extra gauge boson mass



- blue lines: m_{A_H}
- green lines: m_{Z_H}
- mixing angle (θ, θ') dependence: few hundred GeV

Limit on contact term from LEP2

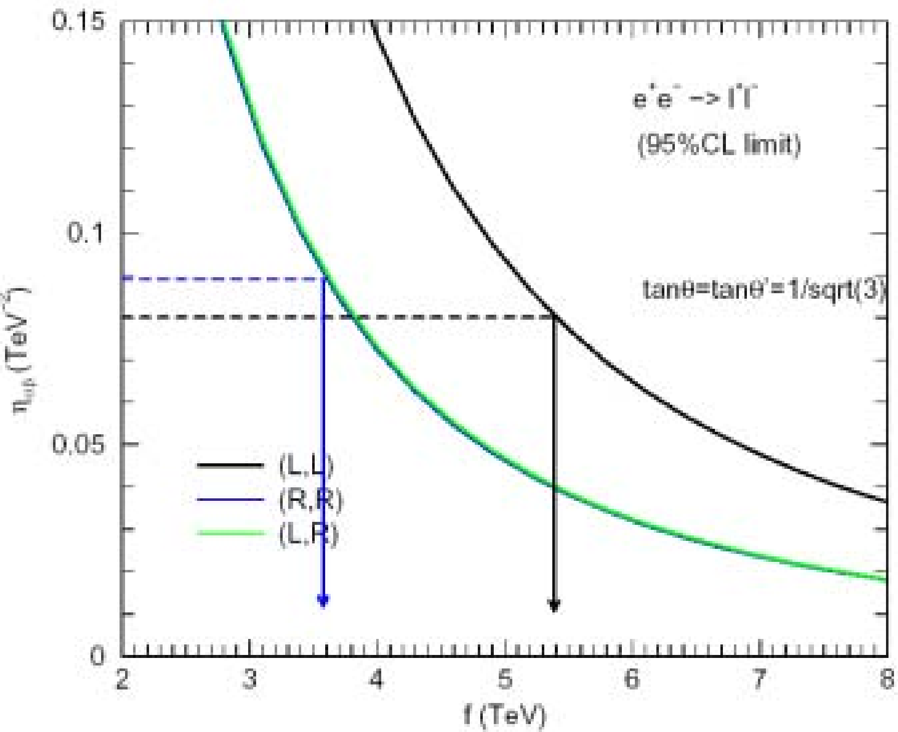


$$\mathcal{L} = \eta^{ff'}_{\alpha\beta}\,\bar{f}\gamma^{\mu}P_{\alpha}f\,\bar{f}'\gamma_{\mu}P_{\beta}f'$$

$$\eta^{ff'}_{\alpha\beta} \sim g^{f}_{\alpha}g^{f'}_{\beta}/M^2$$

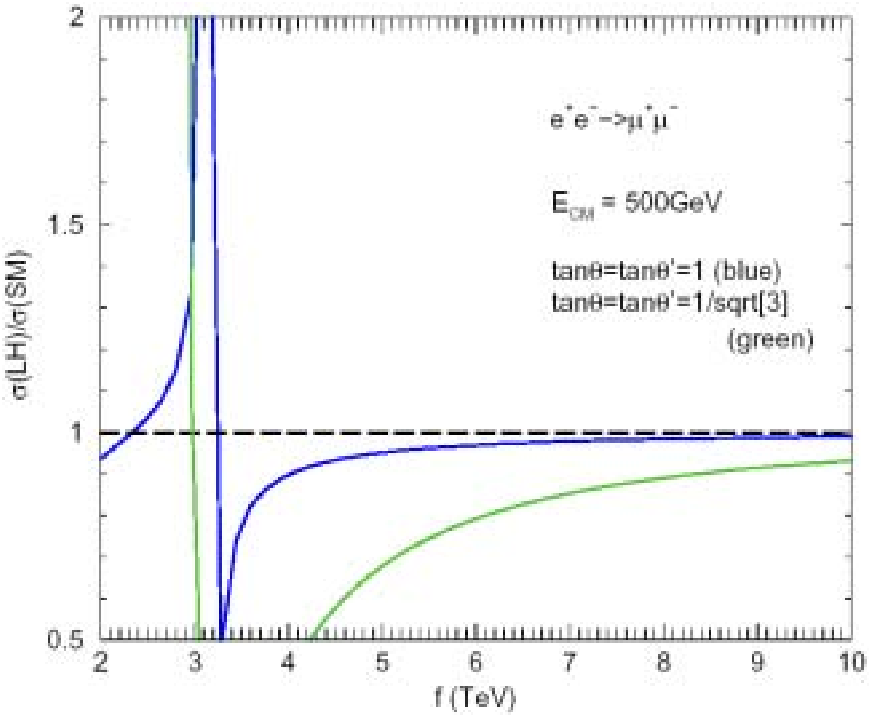
- mixing angle:
  $\tan\theta = \tan\theta' = 1$
- 95%CL bound on the decay constant *f*
  - (L,L) mode: 1.5 TeV
  - (R,R) mode: 1.8TeV

Limit on contact term from LEP2



- mixing angle:
  $$\tan\theta = \tan\theta' = 1/\sqrt{3}$$
- bound on the decay constant f is much severe than the previous case
- 95%CL bound on f
  - (L,L) mode: 5.4 TeV
  - (R,R) mode: 3.5 TeV

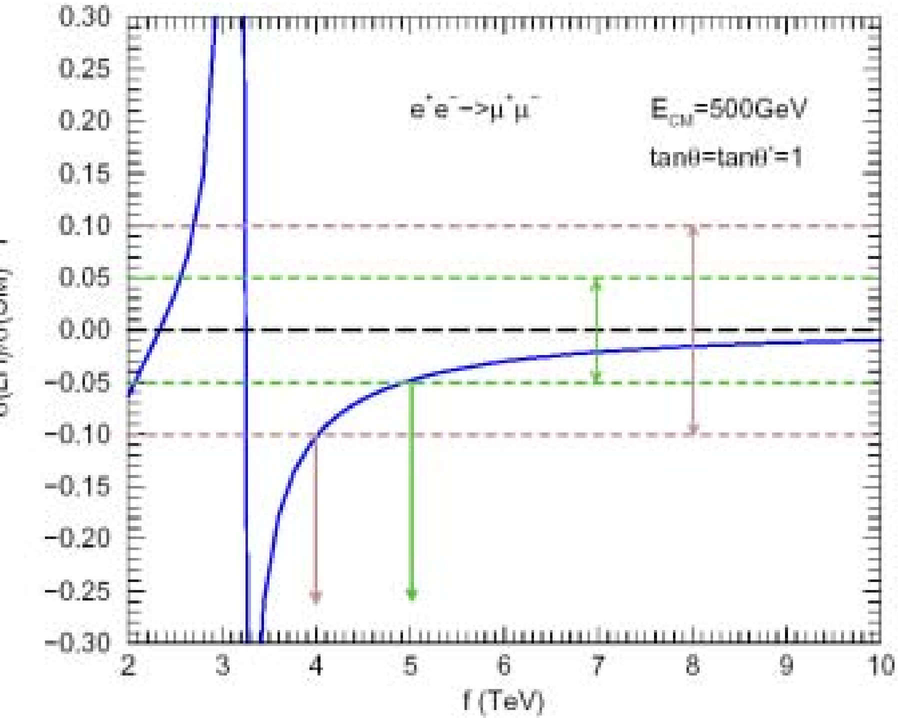
$e^+e^- \to \mu^+\mu^-$ *at LC*



$\sigma(LH)/\sigma(SM)$

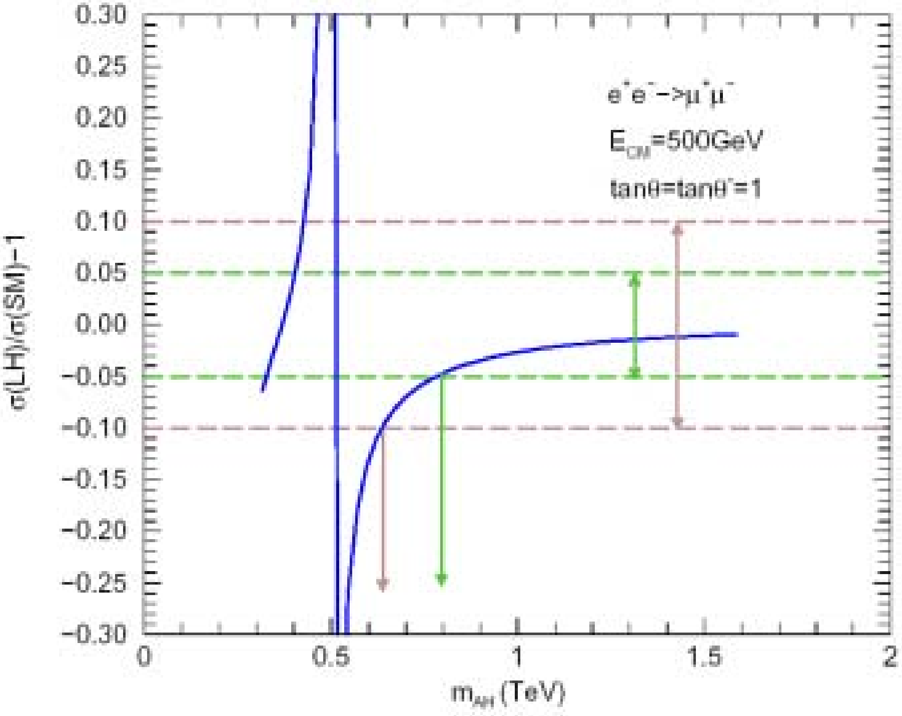
- CM energy: $\sqrt{s} = 500\text{GeV}$
- mixing angle
  $\tan\theta = \tan\theta' = 1$(blue)
  $\tan\theta = \tan\theta' = 1/\sqrt{3}$(green)
- $@\ f \sim 3\text{TeV}$
  $\Rightarrow m_{A_H} \sim 500\text{GeV} \sim \sqrt{s}$

Bound from measurements at LC



- compare with
  $\sigma(\text{exp.})/\sigma(\text{SM}) - 1$
- mixing angle
  $\tan\theta = \tan\theta' = 1$
- if the measurement accuracy is better than 10%, $f \geq 4\text{TeV}$

Bound on the extra gauge boson A_H



- mixing angle

$$\tan\theta = \tan\theta' = 1$$

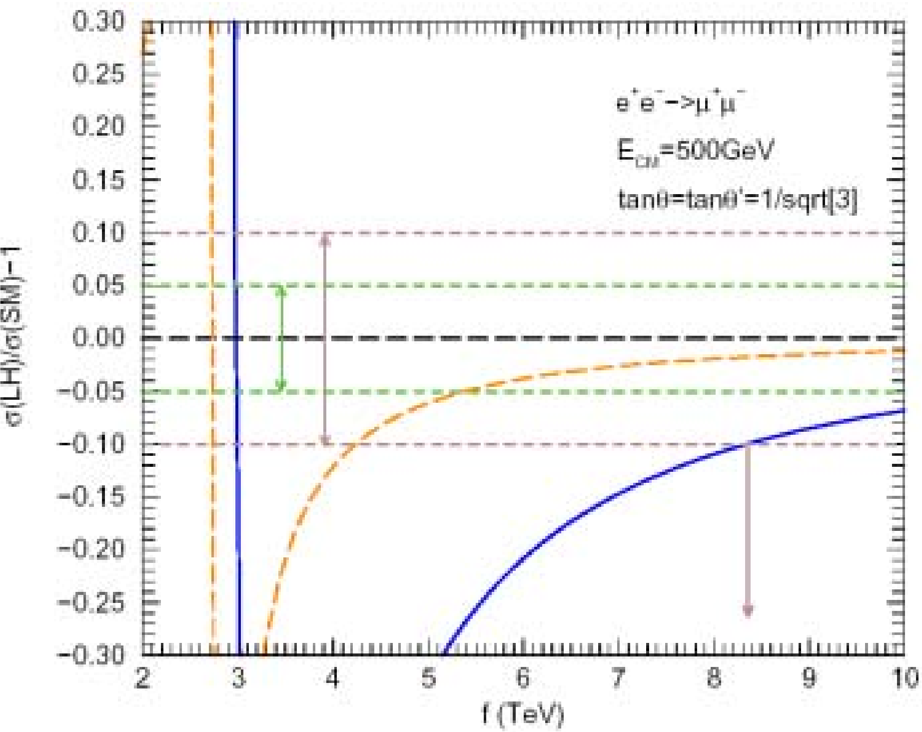
- 10% accuracy

$$m_{A_H} \geq 0.6\text{TeV}$$

- 5% accuracy

$$m_{A_H} \geq 0.8\text{TeV}$$

Bound from measurements at LC



- mixing angle

  $$\tan\theta = \tan\theta' = 1/\sqrt{3}$$

  ($\sqrt{3}$ for orange line)

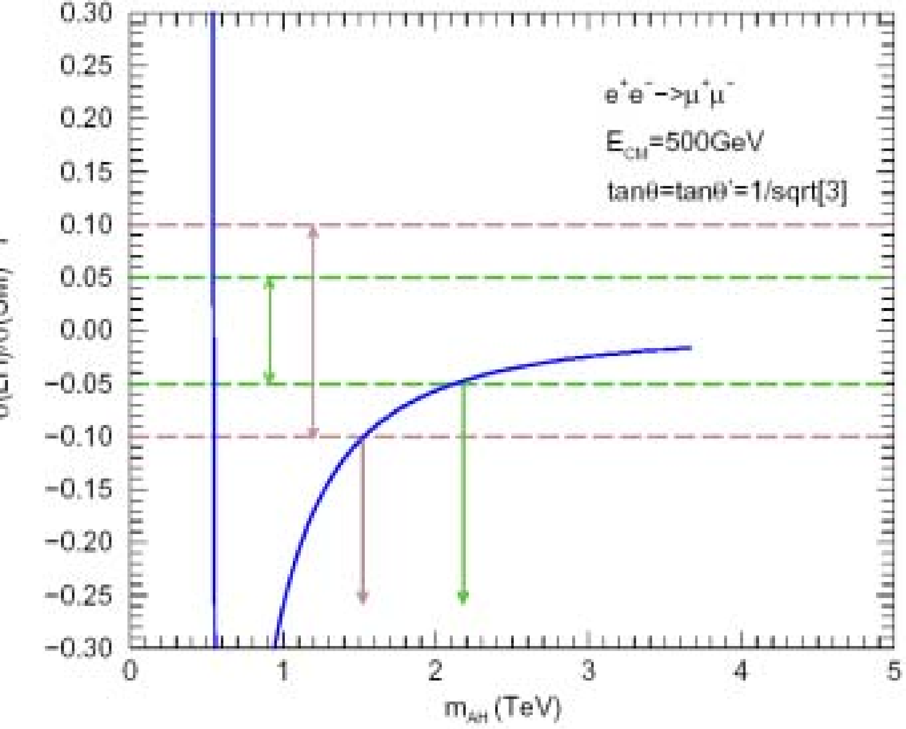
- 10% accuracy leads to

  $$f \geq 8\text{TeV}$$

- 5% accuracy:

  $$f \geq 10\text{TeV}$$

Bound on the extra gauge boson A_H



- mixing angle

$$\tan\theta = \tan\theta' = 1/\sqrt{3}$$

- 10% accuracy

$$m_{A_H} \geq 1.6\text{TeV}$$

- 5% accuracy

$$m_{A_H} \geq 2.2\text{TeV}$$

Summary

- Constraints on the Littlest Higgs model at LC are studied (extra gauge bosons, A_H, Z_H)

- $e^+e^- \to \mu^+\mu^-$: interference effect

  $f \geq 4 \sim 6\text{TeV}$ may be expected

  $(m_{A_H} \geq 2\text{TeV})$

  – (cf) triple gauge boson vtx. (Han etal)

    $f \sim 12\text{TeV}$ expected