Littlest Higgs Model and W Pair Production at ILC

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- Alternative models include composit higgs models, models with strongly interacting EW sector, higgsless models, etc.

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- The EWSB mechanism leaves its signature in the gauge sector of the theory, for the massive gauge bosons get their longitudinal components from the symmetry breaking sector.
- Proposed high energy linear collider (ILC) is expected to produce a large number of gauge boson pairs, where precision measurements are going to scrutinize their couplings, and other properties in detail.

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Plan

- **The Little Higgs Models**
- **The Process: $e^+e^- \to W^+W^-$**
- **Summary**

The Little Higgs Models

- The scenario is analogous to the description of low energy hadronic interactions by a non-linear realisation of the chiral symmetry, $SU(2)_L \times SU(2)_R$, broken down to the diagonal isospin $SU(2)_I$ with pions as pseudo Goldston Bosons.

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- In a specific model, called Littlest Higgs model $G \equiv SU(5)$ broken down to $H \equiv SO(5)$ at a scale f. This gives $24 - 10 = 14$ Goldstone Bosons.
- Gauge group $SU(2)_1 \times SU(2)_2 \times U(1)_Y \subset G$, is broken down to $SU(2)_L \times U(1)_Y$, which is identified as the SM gauge group.

The Little Higgs Models

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- Quadratically divergent corrections to the higgs mass due to the SM gauge bosons cancel with the new heavy gauge boson contributions.

The Little Higgs Models

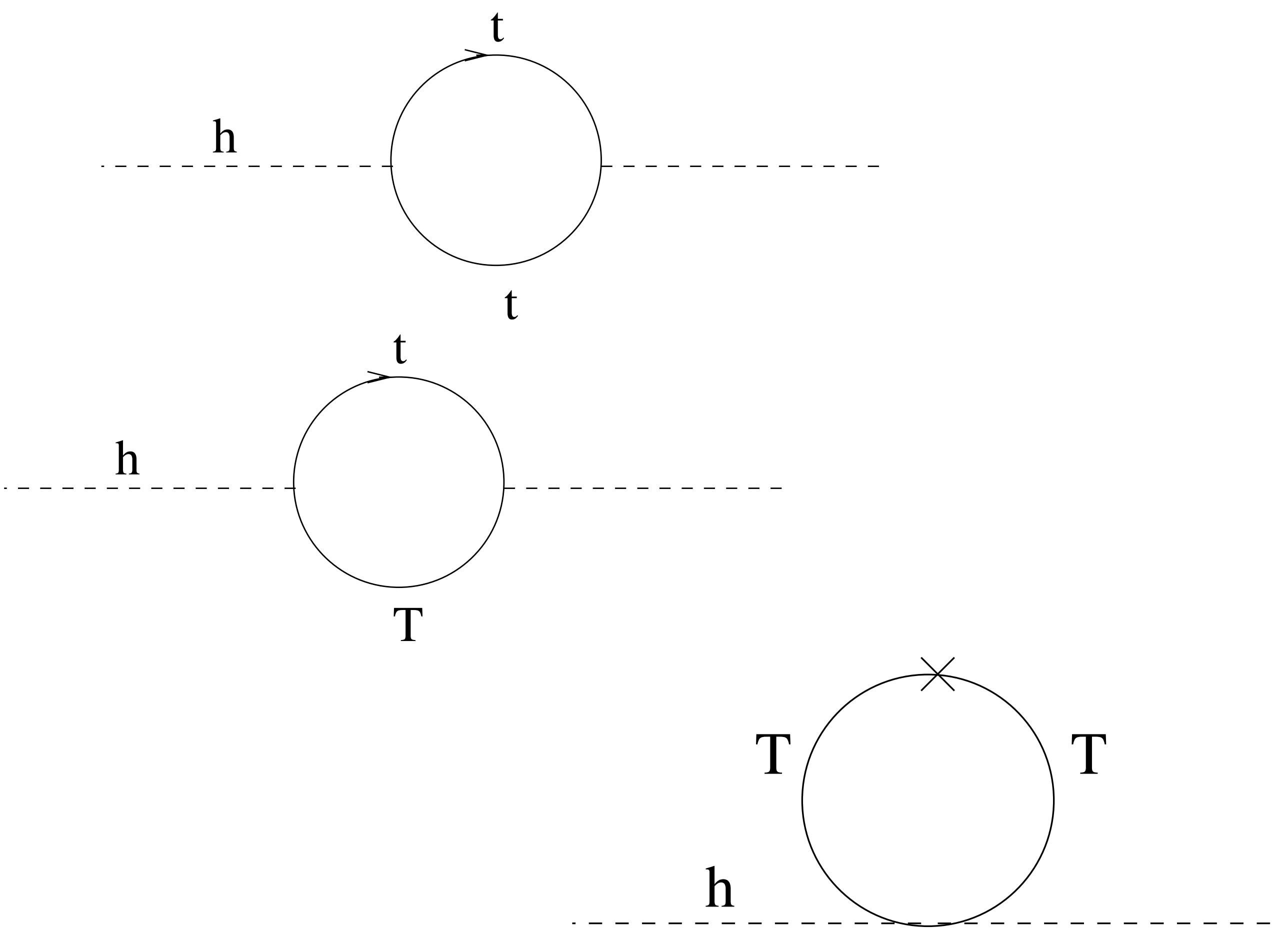
- Yukawa couplings:
  Inorder to avoid quadratic divergence due to top quark loop, a pair of Weyl quark $\tilde{t},\ \tilde{t}^c$ and a weak singlet quark $u_3'^c$ are added, along with the standard left-handed doublet, (t_3, b)
- The top Yukawa coupling terms are given in terms of the mass eigenstates t (the SM top quark with mass m_t) and T (with mass $M_T \geq \sqrt{2}\, f$) as

$$\mathcal{L}_Y = \lambda_t\, ht^c t + \lambda_T\, hT^c t + \frac{\lambda_T'}{2M_T}\, hhT^c T + h.c.,$$

  where
  $\lambda_t = m_t/v, \quad \lambda_T = x_\lambda m_t/v, \quad \lambda_T' = (1 + x_\lambda^2) m_t^2/v^2$.
  x_λ is a parameter (of order 1).

The Little Higgs Models

- Thus at one loop the quadratic contributions cancel between the following diagrams:



The Gauge Sector

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- Three heavy gauge bosons, $W_H^{\pm},\ Z_H$, in addition to the standard $W^{\pm},\ Z,\ A$.

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- Masses

$$M_{W_H} = M_{Z_H} \quad = \quad \frac{g}{\sin 2\theta} f = \frac{0.65}{\sin 2\theta} f$$

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- Real production of heavy gauge bosons occur above a TeV. But their virtual effects may be seen at lower energies.

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- Coupling relevant to this case are given in terms of these parameters f and θ as

$$
\begin{aligned}
g_{WWZ_H} &= \frac{gv^2}{8f^2}\sin 4\theta \\
c^v_{eeZ} &= \frac{g}{2c_W}\left[\left(-\frac{1}{2}+2x_W\right)+\frac{v^2}{f^2}\frac{\sin 4\theta}{8}\right] \\
c^a_{eeZ} &= \frac{g}{2c_W}\left[\frac{1}{2}-\frac{v^2}{f^2}\frac{\sin 4\theta}{16}\cot\theta\right] \\
c^v_{eeZ_H} &= \frac{-g}{4}\cot\theta \\
c^a_{eeZ_H} &= \frac{g}{4}\cot\theta
\end{aligned}
$$

The Gauge Sector

Precision measurements (including LEP2) constrains the parameters

$$f > 1 \ \ TeV, \quad c \sim 1/3$$

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Arkani-Hamed, et.al. *JHEP* **07**(2002) 034;
Han, Logan, Wang, *hep-ph*/0506313;
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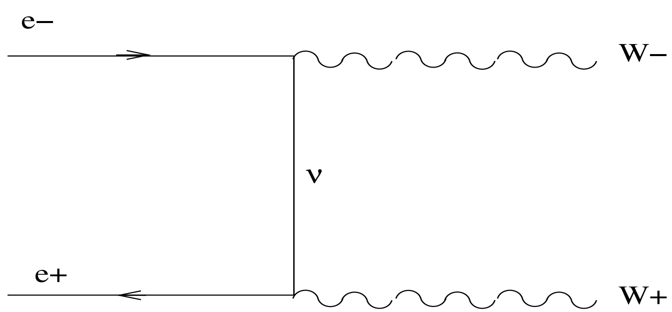
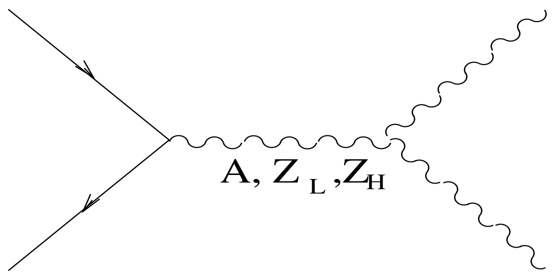
Conley, Hewet, Phuong Le, *hep-ph*/0507198.

$e^+e^- \to W^+W^-$

We will now consider the effect of this scenario in W pair production at a high energy linear e^+e^- collider.

- The process has the following Feynman diagrams:





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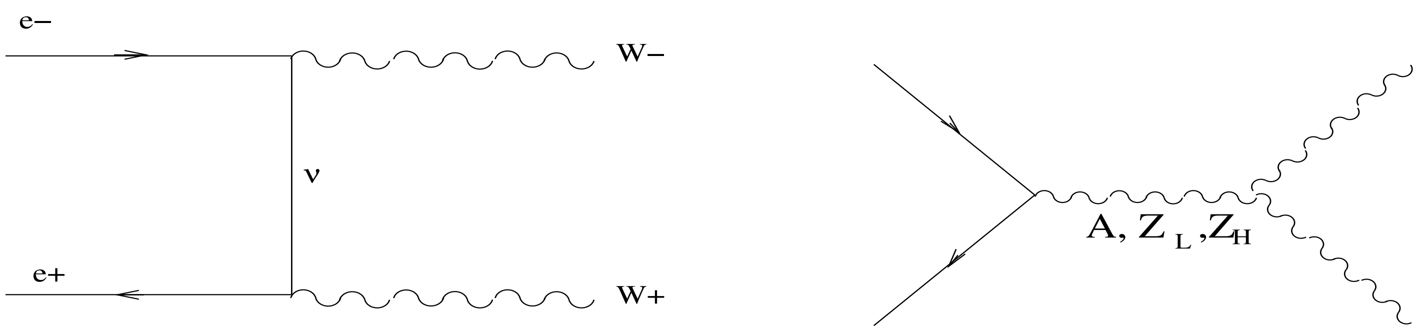

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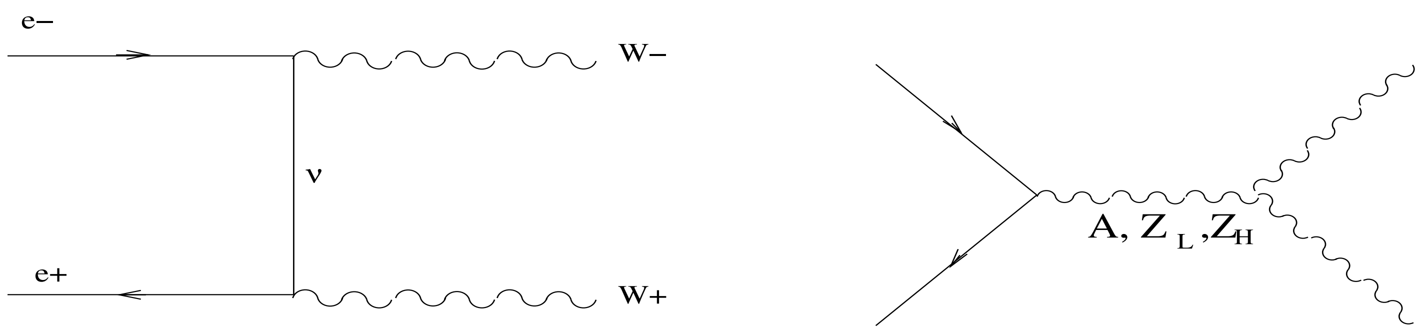
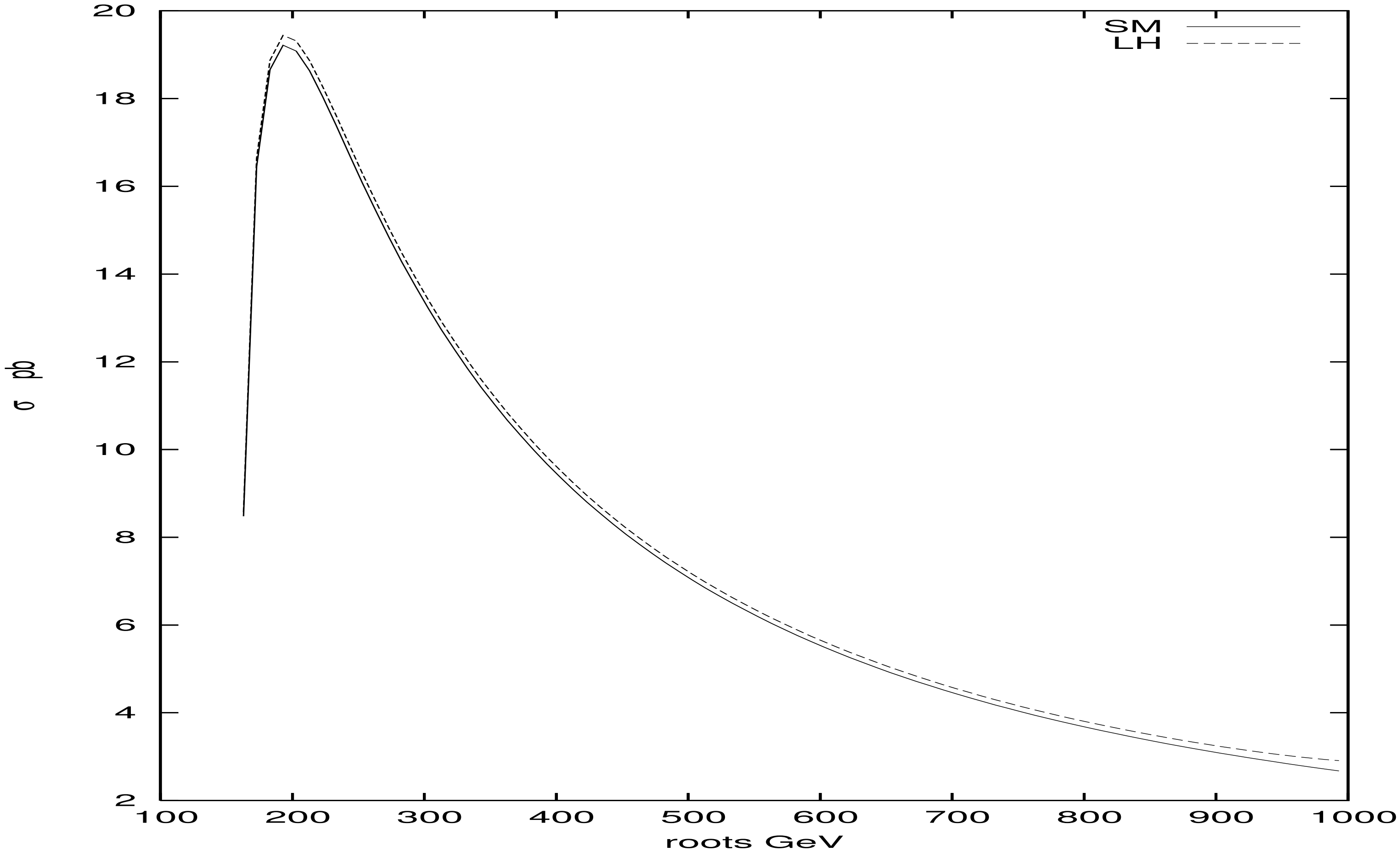
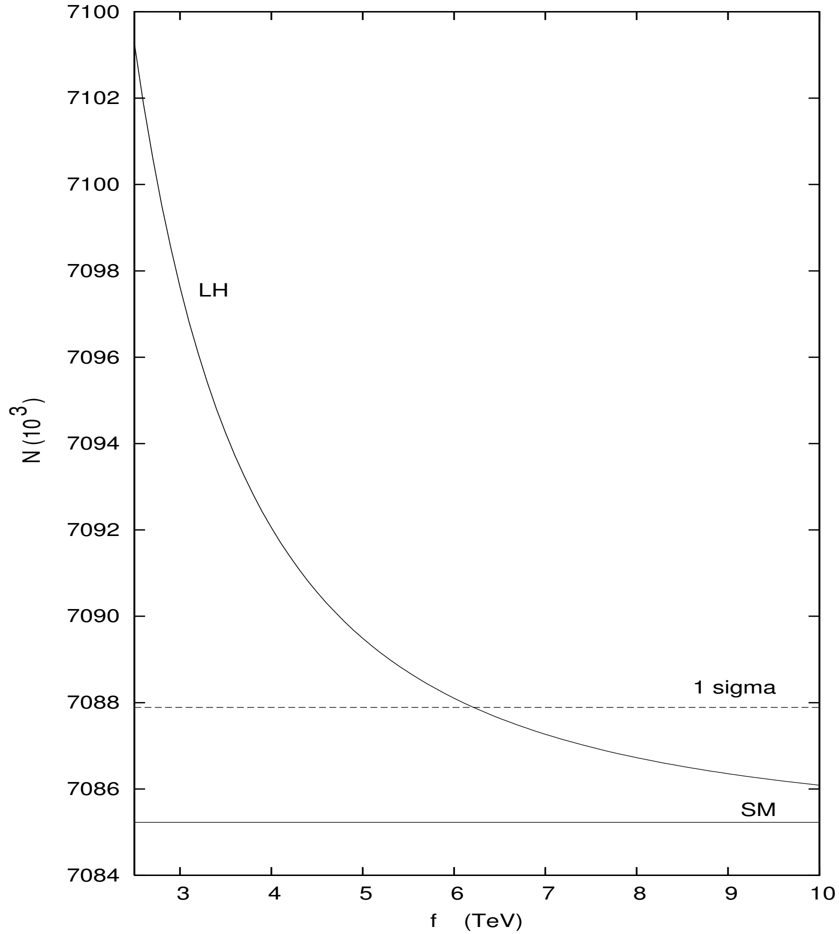


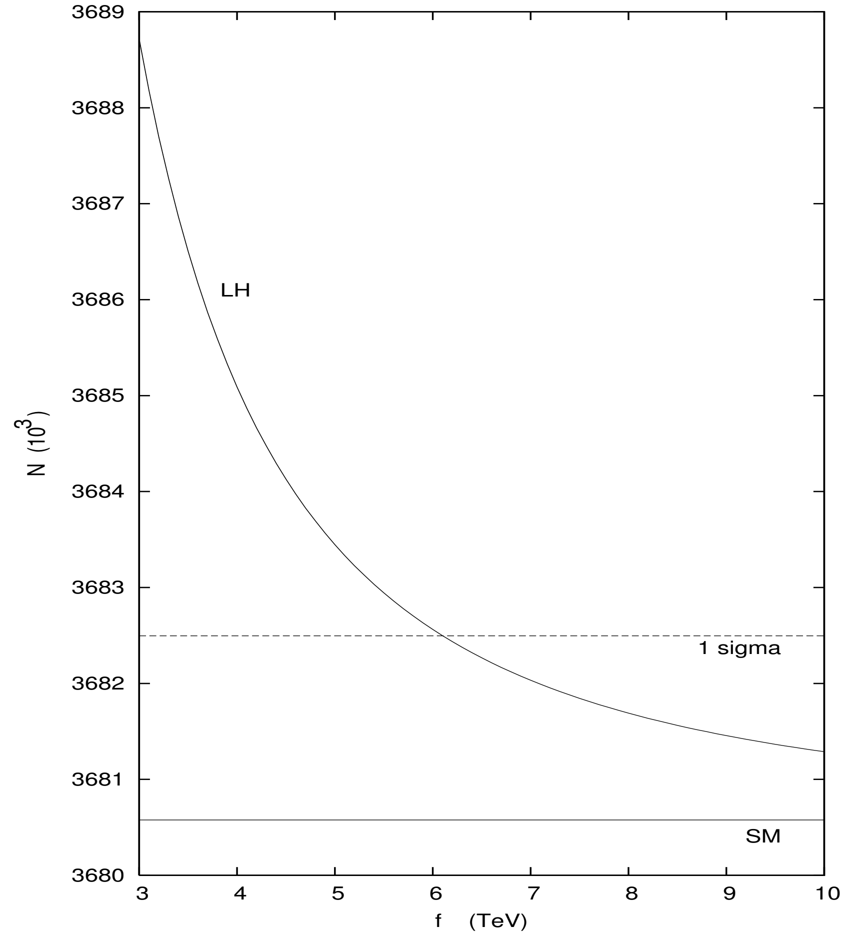
- ILC is going to be operated at energies up to a TeV. A Z_H with mass around a TeV will perhaps show its signs there.
- Owing to the large luminosity expected at the ILC, cross section measurement itself might be a good observable.



$\sqrt{s}$ GeV	σ_{SM} pb	σ_{LH} pb
500	7.1	7.2
800	3.7	3.8



$\sqrt{s} = 500$ GeV



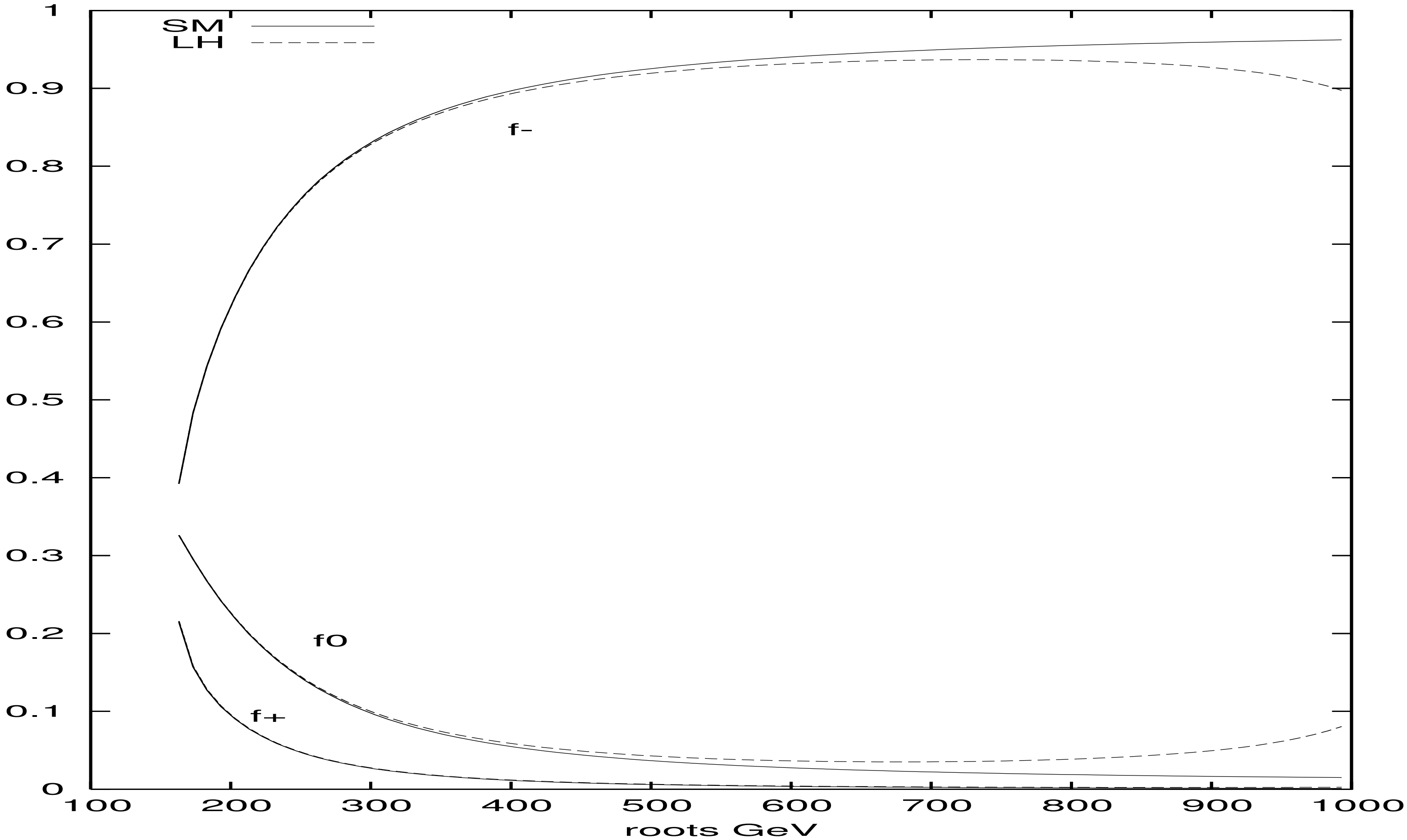
$\sqrt{s} = 800$ GeV

Integrated luminosity: $1\ ab^{-1}$

$1\,\sigma$ limit on f: $\sim 6\,TeV$

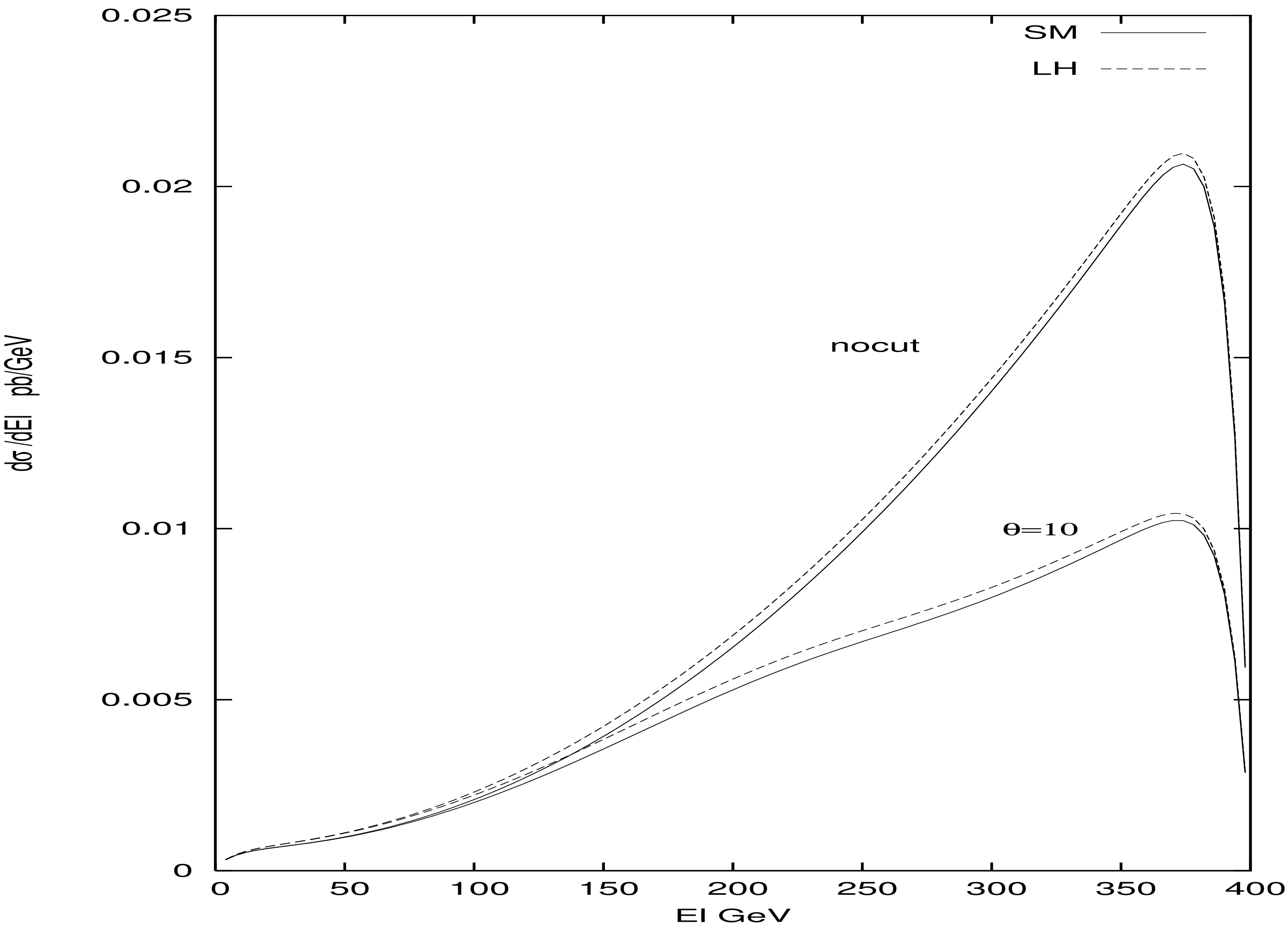
LEP has measured the fractional cross section of the polarised W's very precisely. AT ILC it will be even better. We define

$$f^0 = \frac{1}{\sigma_{unpol}} \sigma(e^+e^- \to W^+W_L^-), \text{ etc.}$$



$\sqrt{s}$ GeV	σ_{SM} pb		f_{SM}%	$f_{LH}\%$
500	7.1	f^0	3.8	4.4
		f^-	95.6	94.9
		f^+	0.6	0.7
800	7.2	f^0	1.9	4.0
		f^-	97.9	95.8
		f^+	0.2	0.2

Energy distribution of the decay leptons.



Summary

- Little Higgs model with a global $SU(5) \to SO(5)$ and a local $SU(2)_1 \times SU(2)_2 \times U(1)_Y \to SU(2)_L \times U(1)_Y$ is a viable alternative to the Standard Higgs mechanism.
- The model has
  - one light neutral higgs with radiatively stable mass.
  - two charged ($W_H^{\pm}$) and one neutral (Z_H) gauge bosons with mass $\sim f$, the symmetry breaking scale.
  - one heavy top quark of mass $\sim \sqrt{2}f$.

- Our analysis to see the effect of this model in $e^+e^- \to W^+W^-$ at a high energy linear collider shows:
  - Considering 1σ deviation at a 500 GeV or 800 GeV ILC with integrated luminosity of $1\,ab^{-1}$ can explore the mass scale up to about $6\,TeV$.

For parameter values

$f = 1$ TeV and $\theta = 0.35$

  - cross section deviates by 1.2% at $\sqrt{s} = 500$ GeV and 3.4 % at $\sqrt{s} = 800$ GeV
  - polarization fractions show measurable deviations.
- Beam polarization is expected to show larger effects. Studies in progress.