Testing Little Higgs Mechanism at Future Linear Colliders

Shigeki Matsumoto (IPMU, Univ. of Tokyo)

Collaboration: K. Harigaya (IPMU)
M. Nojiri (KEK & IPMU)
K. Tobioka (IPMU)

arXiv:1109.4847 [hep-ph]

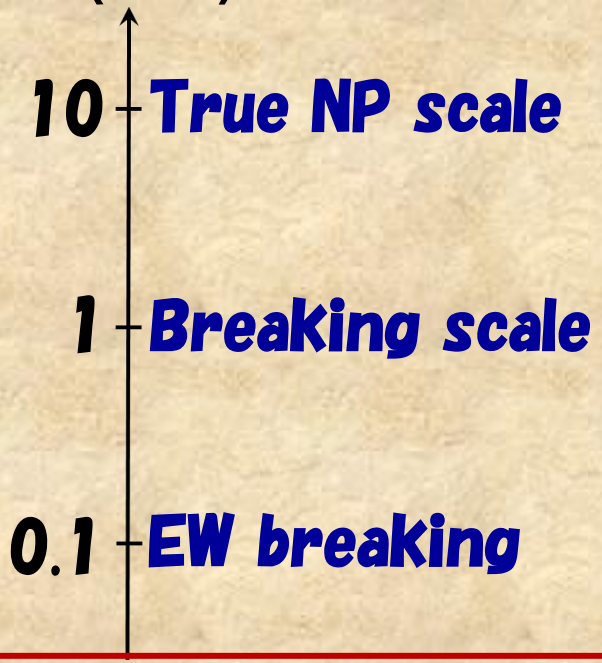
Little higgs scenario predicts a definite relation between coupling constants of interactions (Little higgs mechanism).

Is it possible to confirm the relation at future colliders?
(Here, we focus on the top sector of the scenario.)

Yes, we can confirm the relation by observing higgs associate and threshold productions of top partner.

Little Higgs Scenario

[N. Arkani-hamed, A. G. Cohen, E. Katz, A. E. Nelson (2002)]



NP@10TeV has a global symmetry(G),
[G is slightly broken explicitly.]

1. Higgs boson is a pseudo NG boson.
2. Explicit breaking is arranged to cancel Λ^2 div on m_h at 1-loop Lv.
(Collective symmetry breaking)

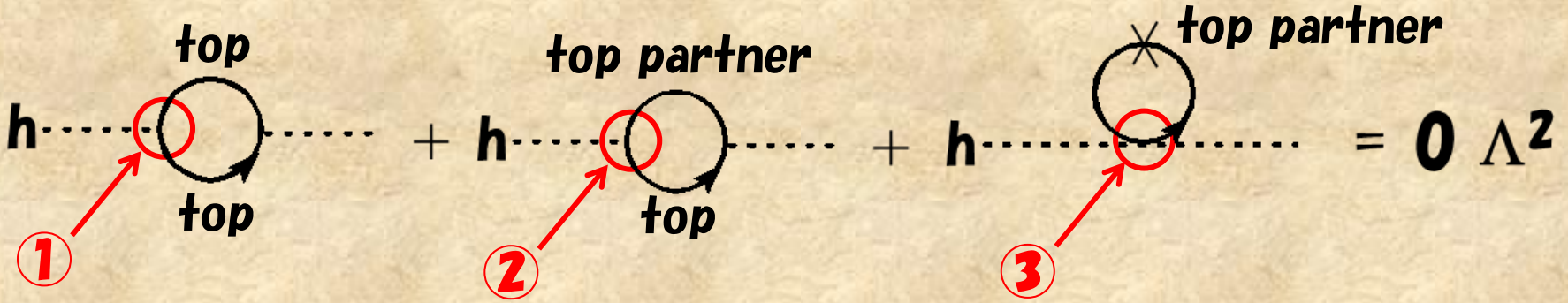
→ New particles of O(1) TeV exist!
(Little Higgs Partners)

Quadratically divergent corrections canceled at 1-loop Lv.

There must be a relation between SM & LH interactions

Little Higgs Mechanism

Top partner = Singlet vector-like particle.



① Top Yukawa interaction (top-top-higgs)

$$-y_3 Q^\dagger H^c u_R^3$$

Already known (from Top mass)

② Yukawa interaction (top-top partner-higgs)

$$-y_U Q^\dagger H^c U_R \quad \rightarrow$$

Inducing top-top partner mixing.
y_U determined by mixing angle (θ_L)
and top partner mass ($m_T \sim m_U$)

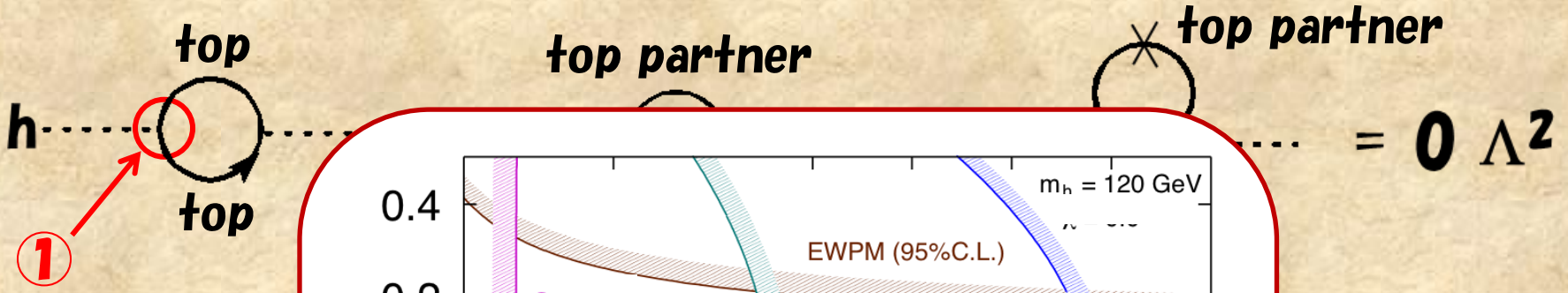
③ Top partner Yukawa interaction (top partner-top partner-higgs)

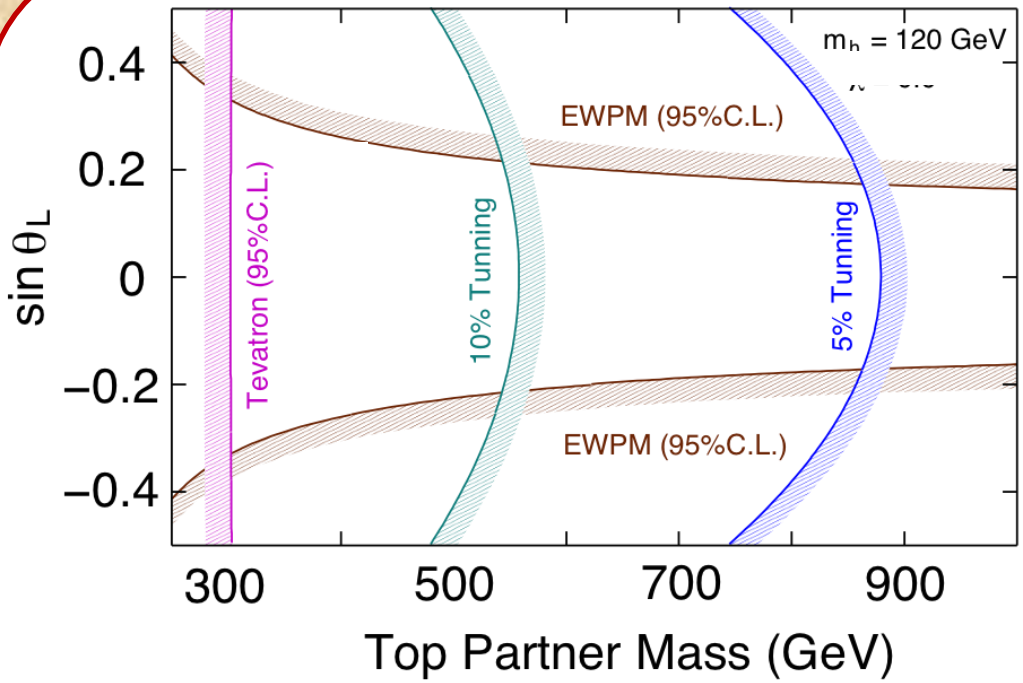
$$-\frac{\lambda'}{m_U} U_L^\dagger U_R |H|^2 \quad \rightarrow$$

Inducing Yukawa interaction of top partner. Processes including the Yukawa int. are important.

Little Higgs Mechanism

Top partner = Singlet vector-like particle.





[Tevatron, CDF & DO collaborations (2011)]
[J Hubisz, P. Meade, A. Noble, M. Perelstein (2005)]

① Top Yukawa … mass)

② Yukawa inte … mixing. … angle (θ_L) … $m_T \sim m_U$)

$$-y$$

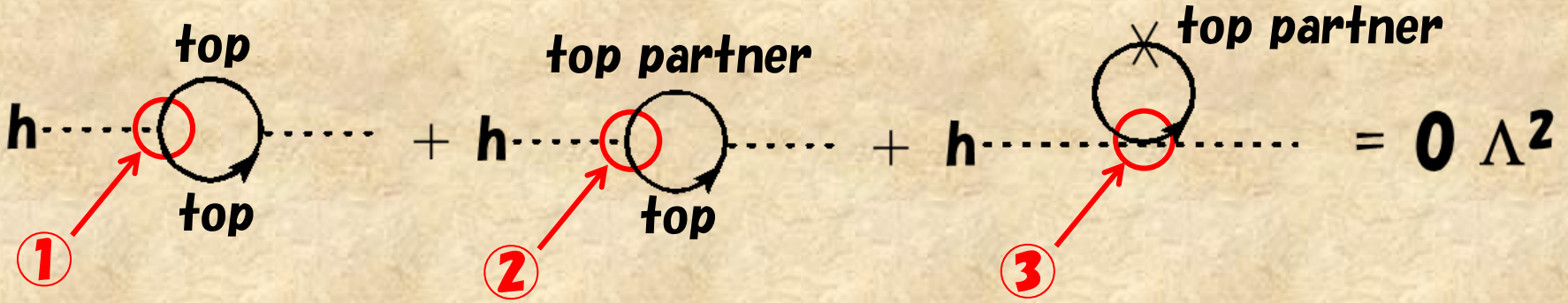
③ Top partner … tner-higgs)

$$-\frac{\lambda'}{m_U} U_L^\dagger U_R |H|^2 \rightarrow$$

inducing Yukawa interaction of top partner. Processes including the Yukawa int. are important.

Little Higgs Mechanism

Top partner = Singlet vector-like particle.



① Top Yukawa interaction (top-top-higgs)

$$-y_3 Q^\dagger H^c u_R^3$$

Already known (from Top mass)

② Yukawa interaction (top-top partner-higgs)

$$-y_U Q^\dagger H^c U_R \quad \rightarrow$$

Inducing top-top partner mixing.
y_U determined by mixing angle (θ_L)
and top partner mass ($m_T \sim m_U$)

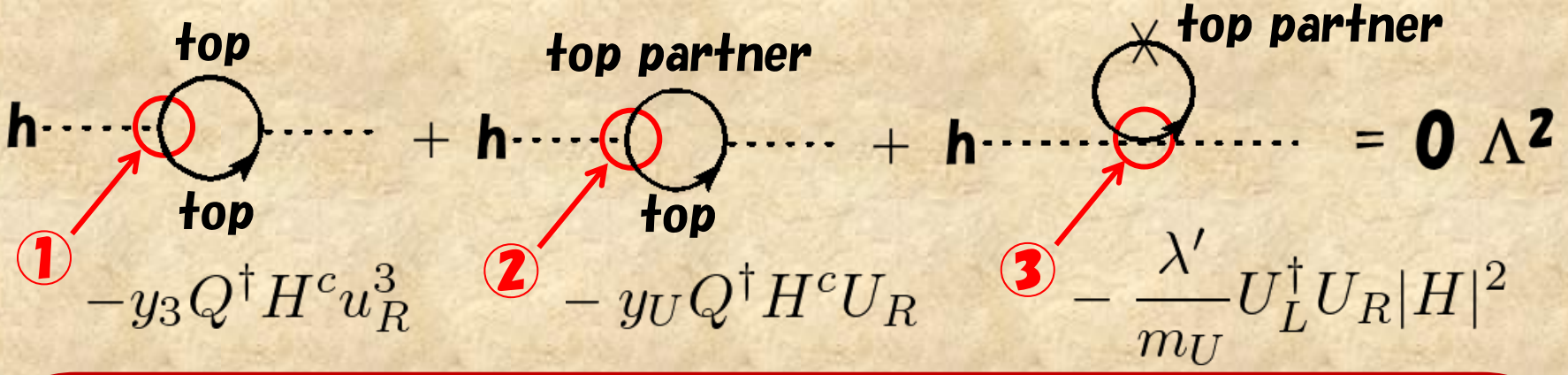
③ Top partner Yukawa interaction (top partner-top partner-higgs)

$$-\frac{\lambda'}{m_U} U_L^\dagger U_R |H|^2 \quad \rightarrow$$

Inducing Yukawa interaction of top partner. Processes including the Yukawa int. are important.

Little Higgs Mechanism

(We focus on the top sector.)



$$-y_3 Q^\dagger H^c u_R^3 \qquad -y_U Q^\dagger H^c U_R \qquad -\frac{\lambda'}{m_U} U_L^\dagger U_R |H|^2$$

In order to cancel quadratically divergent corrections to m_h,

$$\lambda' = -\frac{y_3^2 + y_U^2}{2} \equiv \lambda'_{cr}$$

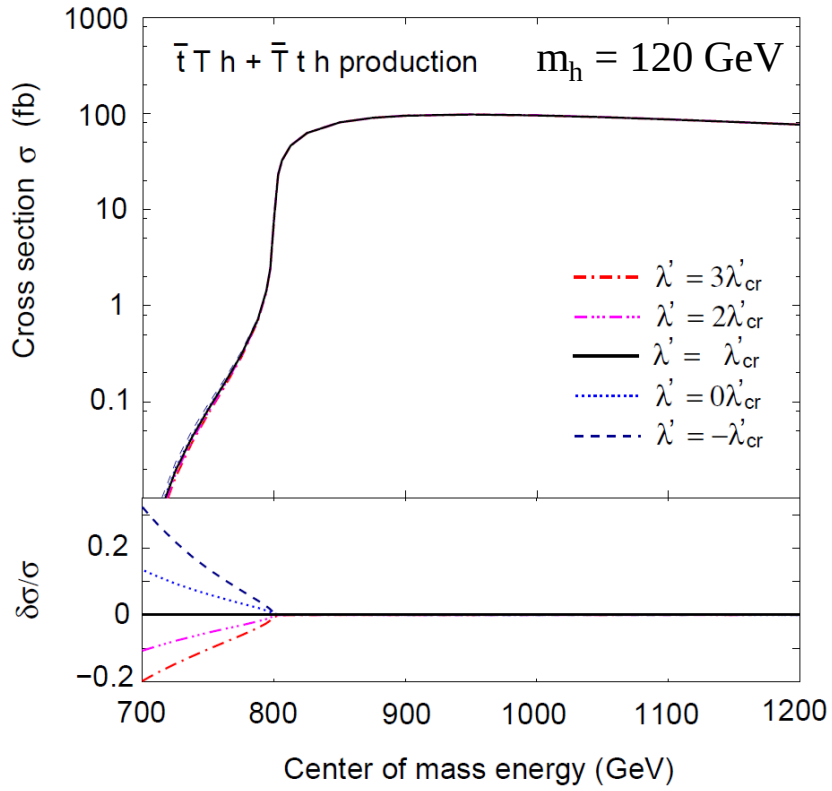
In following discussion, we postulate that coupling constants y_3 & y_U are determined precisely. This is actually true if the top partner is detected at future colliders through pair & single productions.

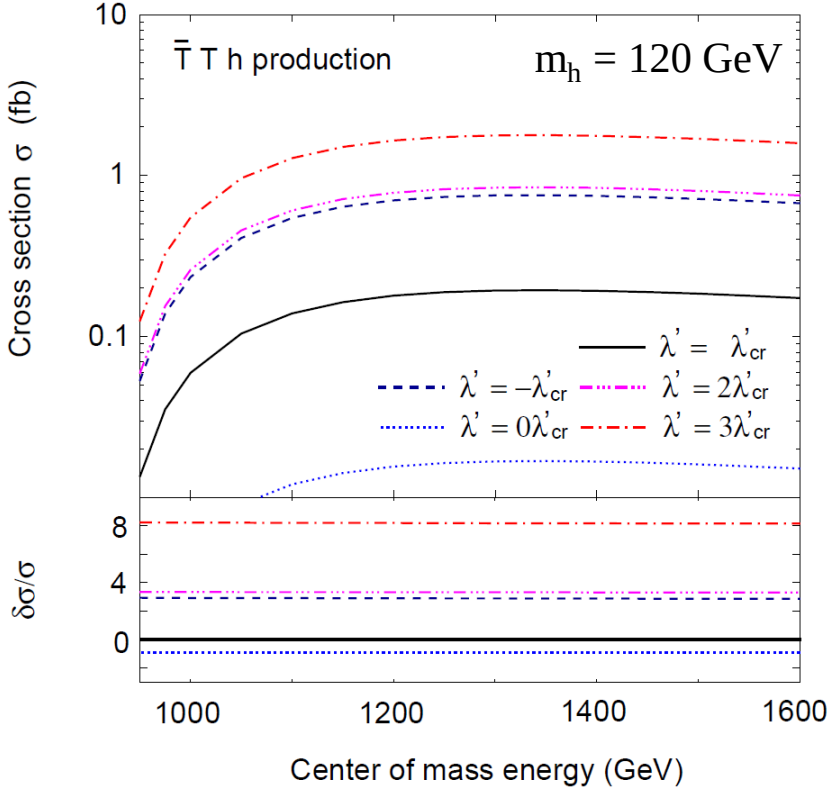
Confirmation of LH Mechanism = Determination of λ'

Sample point: m_T = 400GeV, m_h = 120 GeV, $\sin\theta_L$ = 0.2

For LHC studies, see M. Perelstein, M. E. Peskin, and A. Pierce, PRD69 (2004)

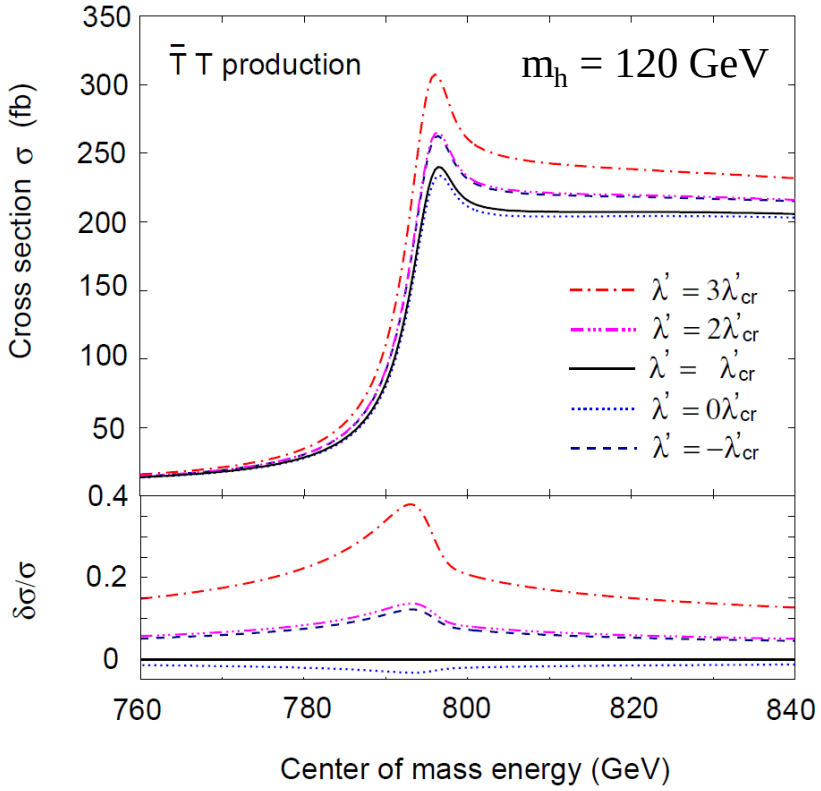
Higgs Associate productions of top partner

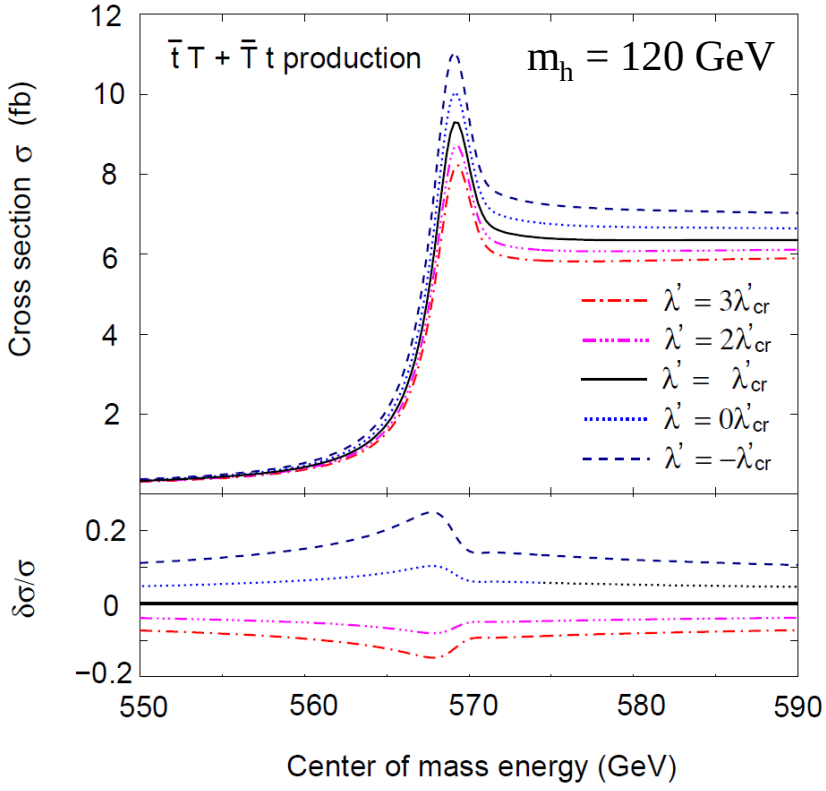




- **Tth production:** Real TT production opens when $s^{1/2} > 800$ GeV. Below 800 GeV, X-section is too small to detect small $\delta\sigma/\sigma$ difference.
- **TTh production:** $\delta\sigma/\sigma$ is large enough to determine parameter λ' when the center of mass energy $s^{1/2}$ is large.

Threshold productions of top partner

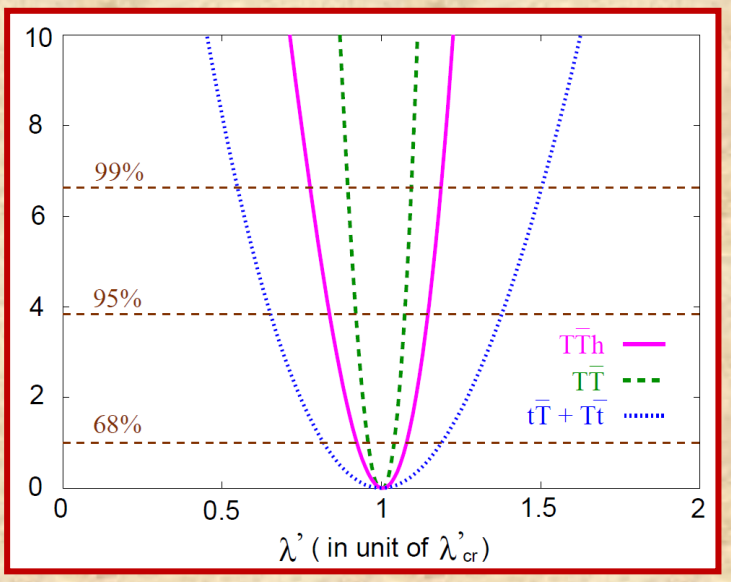




[M. J. Strassler, M. E. Peskin, (1991)]

- **TT production:** Cross section is quite large & $\delta\sigma/\sigma$ is not small at the peak of the resonance.
- **Tt production:** Cross section is still large & $\delta\sigma/\sigma$ is not small. Too large center of mass energy is not needed!

Discussion & Summary



1. It is possible to confirm the little higgs mechanism at future linear colliders.
2. Using higgs associate process ($ee \to TTh$), the parameter λ' can be determined with $\sim 8\%$ accuracy when $L_{eff} = 500fb^{-1}$.
3. Using the threshold production of top partner pair ($ee \to TT$), the parameter λ' can be determined with $\sim 4\%$ accuracy when $L_{eff} = 500fb^{-1}$.
4. Using the threshold production of top quark and top partner ($ee \to Tt$), the parameter λ' can be determined with $\sim 20\%$ accuracy when $L_{eff} = 500fb^{-1}$. Center of mass energy does not have to large in this case.

Backup 1

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
Q	3	2	1/6
u^3_R	3	1	2/3
U_L	3	1	2/3
U_R	3	1	2/3
H	1	2	1/2

$$-m_U U_L^\dagger U_R + h.c.$$

$$-y_3 Q^\dagger H^c u_R^3 - y_U Q^\dagger H^c U_R + h.c.$$

$$-\frac{\lambda}{m_U} U_L^\dagger u_R^3 |H|^2 - \frac{\lambda'}{m_U} U_L^\dagger U_R |H|^2 + h.c.$$

Backup 2

$$H \to \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v+h \end{pmatrix} \Rightarrow -m_t \bar{t}t - m_T \bar{T}T - y_t \bar{t}th - y_T \bar{T}Th - (\bar{T}(\lambda_R P_R + \lambda_L P_L)th + h.c.)$$

$$\begin{pmatrix} t_L \\ T_L \end{pmatrix} = \begin{pmatrix} \cos\theta_L & -\sin\theta_L \\ \sin\theta_L & \cos\theta_L \end{pmatrix} \begin{pmatrix} u_L^3 \\ U_L \end{pmatrix}$$

$$\begin{pmatrix} t_R \\ T_R \end{pmatrix} = \begin{pmatrix} \cos\theta_R & -\sin\theta_R \\ \sin\theta_R & \cos\theta_R \end{pmatrix} \begin{pmatrix} u_R^3 \\ U_R \end{pmatrix}$$

$$m_t \simeq \frac{y_3 v}{\sqrt{2}} \qquad m_T \simeq m_U - \frac{y_3^2 v^2}{4 m_U}$$

$$y_t \simeq \frac{1}{\sqrt{2}} y_3 \qquad y_T \simeq \frac{sin\theta_L}{\sqrt{2}} y_U + \frac{v}{m_U} \lambda'$$

$$\lambda_R \simeq \frac{sin\theta_L}{\sqrt{2}} y_3 \qquad \lambda_L \simeq \frac{1}{2} y_U$$