New Physics in Top Couplings

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Intro

• The top mass is large

  EWSB is communicated strongly to the top; models that modify the symmetry breaking sector can uniquely alter the top’s couplings to the W & Z.

  Strongly-coupled models, Little Higgs models, and yes, even SUSY models can shift the top quark couplings.

• Direct production of the new physics may be kinematically inaccessible. Maybe 1/100 is natural!

• Model independent, direct measurements, of the top quark couplings are crucial (for verification, discovery, and exclusion).
**Shifts in top couplings**

4th generation mixing: GIM mechanism, only the W–t–b coupling is affected

Little Higgs theories (Topcolor, too)
- Mixing with a electroweak singlet
  \[ \lambda_{t_A}' H Q t^c + \lambda_{t_B}' H Q T^c + m_{T_A}' T t^c + \lambda_{T_B}' T T^c \]
  \[ (EW SB) \rightarrow m_t t t^c + m_T T T^c \]

- Littlest Higgs, Simplest Higgs, Minimal Moose, ... T–Parity.
  Could be combined with gauge boson mixing or not.

- T–Parity: No mixing with heavy gauge bosons, but mixing with a singlet Top. Corrections depend on
  \[ \lambda_T h^0 T t^c \]
  \[ m_T \]
  and are of order \( O \left( \frac{\lambda_T^2 v^2 g}{m_T^2} \right) \)
Shifts in top couplings

\[ H, \bar{H} \]

\[ SU(2)_1 \sum SU(2)_2 \]

- A possibility for flavor: explains why the third generation is ‘off’ (mass, mixing)

- Useful for addressing the SUSY little hierarchy problem.

- The observed W, Z are linear combinations of SU(2)_1 and SU(2)_2 gauge bosons--\[ \rho \] corrections only at order \[ \left( \frac{v^2}{f^2} \right)^2 \].

- For small \( \cos(\phi) \), significantly modified couplings for the third generation *only*. Shifts in couplings are from light-heavy mixing due to the Higgs vev: \( \mathcal{O} \left( \left( \sin \phi \right)^4 \frac{v^2}{f^2} \right) \).
Expected Limits on SM-like top couplings

\[ \frac{\Delta g_{L}}{g_{L}}(Wtb) \]

\[ \frac{\Delta g_{A}}{g_{A}}(Ztt) \]

\[ \text{LHC} \]

\[ \text{ILC} \]

4th Gen.

T-Parity:

\[ m_T = 500 \text{ GeV}, \lambda_T \text{ specified} \]

TopFlavor:

\[ \sin \phi = 0.9, \ m_{Z'} \text{ indicated} \]
Single-top is hard at the ILC!

$t\bar{t}$ production dominates (~50 x greater) above threshold and is insensitive to the W-t-b coupling.

The 3 dominant single-top diagrams always have an additional real $W$ and $b$!

Production x Decay: \[ \sigma \propto g_{Vt\bar{t}}^2 \times \left\{ \frac{g_{Wtb}^2}{m_t^2 g_{Wtb}^2} \right\}^2 \]

Difficult to use single-top to measure $g_t \bar{t}_L W b_L$ without getting killed by the $t\bar{t}$ background.
Below Threshold Sensitivity

Simple observation: Below the $t\bar{t}$ threshold, sensitivity is regained:

$$\sigma \propto \frac{g_{Wtb}^2}{\left(q_{t^*}^2 - m_t^2\right)^2 + m_t^2 \Gamma_t^2}$$

the virtual $t^*$ produces a dependence on the $W$-t-b coupling.

How much does this add to the single-top rate when trying to determine the left-handed $W$-t-b coupling?
$g_{Wtb} / g_{SM} = 2$

$g_{Wtb} / g_{SM} = 1$

$g_{Wtb} / g_{SM} = 0.5$

Sensitivity vs Energy

$\sigma$ (fb)

$\sqrt{S}$ (GeV)
Sensitivity vs Energy

Difference/(SM)$^{1/2}$ vs $s^{1/2}$

- $g/g_{SM} = 2$
- $g/g_{SM} = 0.5$

Events

Graph showing sensitivity vs energy with two lines representing different values of $g/g_{SM}$.
$g_{Wtb}/g_{SM} = 2$
$g_{Wtb}/g_{SM} = 1$
$g_{Wtb}/g_{SM} = 0.5$

Sensitivity vs Energy

$\sigma$ (fb)

$\sqrt{S}$ (GeV)
Signal estimation

- “Golden Channel” Semileptonic final state, triggering on the lepton and missing E_T

- Assume 100 fb^{-1}. For some scale, the standard top threshold scan is 30 fb^{-1} across 10 pts (one “well” below threshold). Could spread the needed luminosity across a few below–threshold points.

- Require 2 b–tags (each ~ 70 %)

- Require a top mass and W mass reconstruction (without assuming b–charge) from both the leptonic and hadronic decay.

- LO, fully interfering, estimates (MadEvent), statistical errors

- mistag background small; the dominant background is from real WbWb production through intermediate Higgs and/or Z. Could beat down further with invariant mass rejections. Purity of final sample is very high.

- We estimate the event rate by multiplying each WbWb(g, Γ) with the monte–carloed SM efficiency that pass our cuts (~15%). (branching fractions + kinematic cuts)
@ 340 GeV (Semileptonic final state)

Events/2 GeV

\( m_t \)

No Cuts

After Cuts
$\sqrt{S} = 340$ GeV

$\Gamma_t$ vs. $g_{Wtb}/g_{SM}$
Conclusions

$\delta g_A/g_A (Z_{tt})$

$\delta g_L/g_L (Wtb)$

4th Gen.

Top Flavor

T-Parity

LHC

ILC

$\pm 0.2$

$\pm 0.1$

0

$t t^*/$ singletop at the ILC!
Physics models that address the hierarchy problem often predict shifts in the gauge–boson–top couplings. Model–independent, direct measurements of these couplings are needed.

Precise measurements of \( g \bar{t}_L W b_L \) at an e\(^+\) e\(^-\) collider are challenging at the ILC due to low statistics and a large \( t\bar{t} \) background.

\( t t^* \) contributions do depend (unlike \( t t \)) on \( g \bar{t}_L W b_L \) and enhance the ‘single–top’ like signal.

A 3\% measurement is possible in the semi–leptonic channel, can help rule out many models of BSM physics!
Expected Limits on SM-like top couplings

- $t\bar{t}Z$ production
- $t\bar{t}$ production
- Single $t$ production

Abe et al.
Baur, Juste, Orr, Rainwater
Beneke et al.