Higgsless Models @ One-Loop

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(based on hep-ph/0703299)

The Model(s)

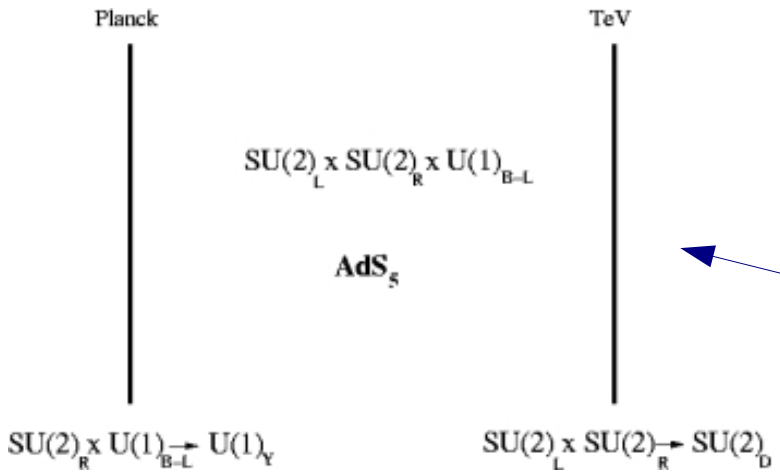
"Generic" Calculation of *S* and *T*

Pinch Technique

Application to the Three Site Model (3SM)

Brookhaven Forum 2007: New Horizons @ Colliders

The Model(s)



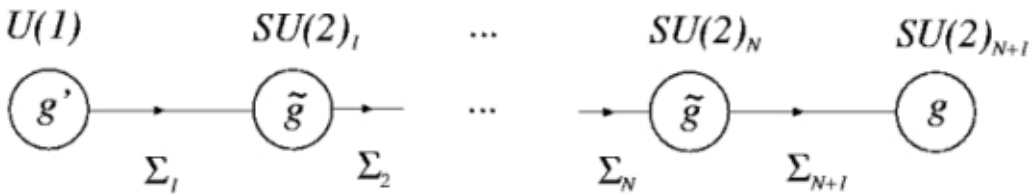
Extra-dimensional:

(Csaki et al., PRD 69: 055006, 2004)

Non-trivial BC's break symmetries
➞ Massive *W* and *Z*

Deconstructed:

(Foadi et al., JHEP 040: 042, 2004)



EWSB described by coupled non-linear sigma models

Related Features: 1) Spectrum = **SM plus "towers" of *W*'s and *Z*'s**

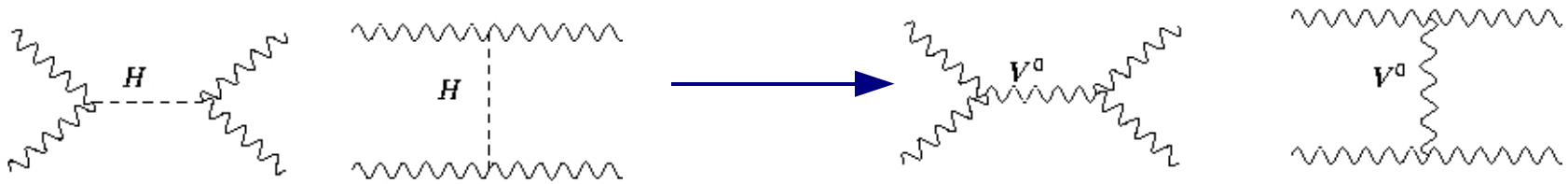
2) Non-renormalizable → **EFT's up to Λ** (~5-10 TeV)

3) **Three scales**: $M_W^2 \ll M_{W'}^2 \ll \Lambda^2$

4) Incorporate **custodial symmetry** (ρ = 1)

Motivation to Get Loopy

Original proposal: unitarity in $V_L V_L$ ($V = W, Z$) scattering w/o a Higgs



W' and Z' have suppressed couplings to fermions...tough even @ LHC(?)

(Birkedal et al., hep-ph/0412278)

Precision EW Data?

***T* parameter small** (due to custodial symmetry)

Extended EW sector → $S \cong 1$

A way out: **fermion delocalization** (Cacciapaglia et al., PRD71: 035015, 2005
Foadi/Schmidt, PRD73: 0705011, 2006)

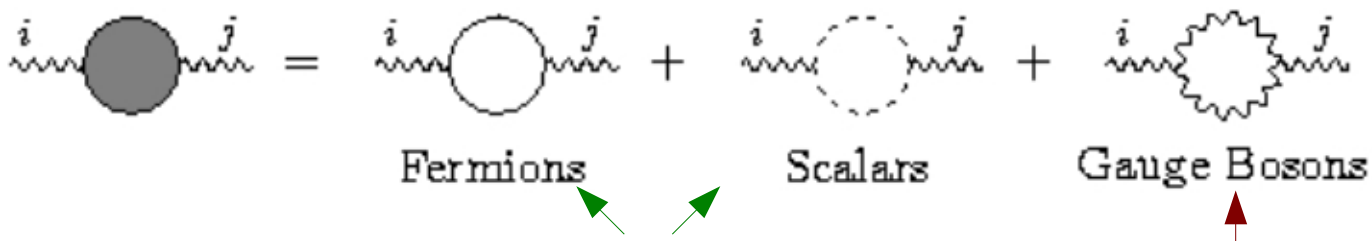
"Dial" tree-level *S* to vanish...while *T* remains small.

To constrain these models → need to go to one-loop!

One Little Problem

$$\frac{\alpha S}{4 s_W^2 c_W^2} = \Pi'_{ZZ}(0) - \Pi'_{\gamma\gamma}(0) - \frac{c_W^2 - s_W^2}{s_W c_W} \Pi'_{Z\gamma}(0) \qquad \alpha T = \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}$$

Classifying contributions to *S* and *T* from New Physics:



Independent of gauge-fixing parameter ξ

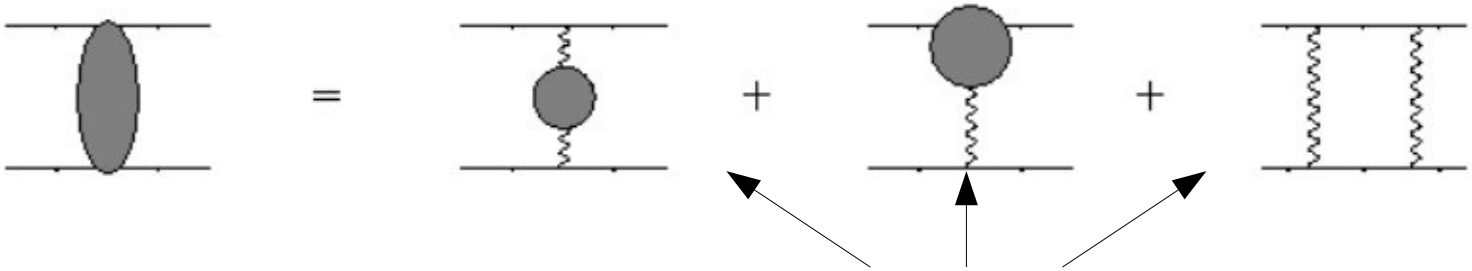
????

DeGrassi/Sirlin (c. 1992): SM gauge boson corrections are **non-trivially dependent** on ξ

$$\Pi_{ij}(q^2) = \Pi_{ij}(q^2)|_{\xi=1} + f_{ij}(\xi_i, q^2, M_W, M_Z)$$

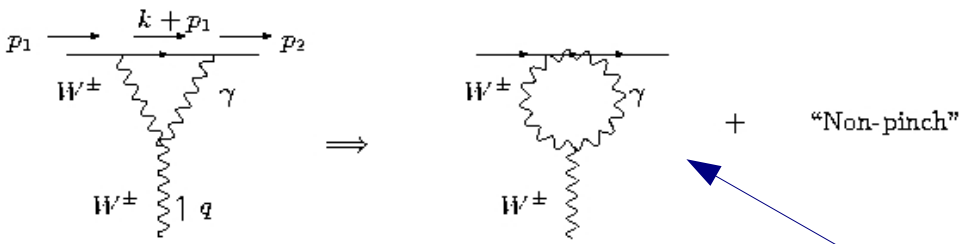
Gauge-dependent terms do not cancel in expression for *S* and *T* !!!

The Pinch Technique (PT)



Gauge-independent **Individually gauge-dependent**

<u>Pinch Technique</u>: isolate "propagator-like" corrections from vertex/box diagrams which contain R_ξ gauge-dependent terms



Add "pinch" pieces to two-pt. functions ($\equiv \Pi^{PT}$)

Gauge-independent *S* and *T*: $\Pi \rightarrow \Pi^{PT}$

Application to a Generic Higgsless Model

Objective: **"recipe"** for calculating *S* and *T* @ one-loop in ~~**Higgs**~~ **models**

Some Details:

Spectrum: SM *plus* (at least) one extra set (W', Z')

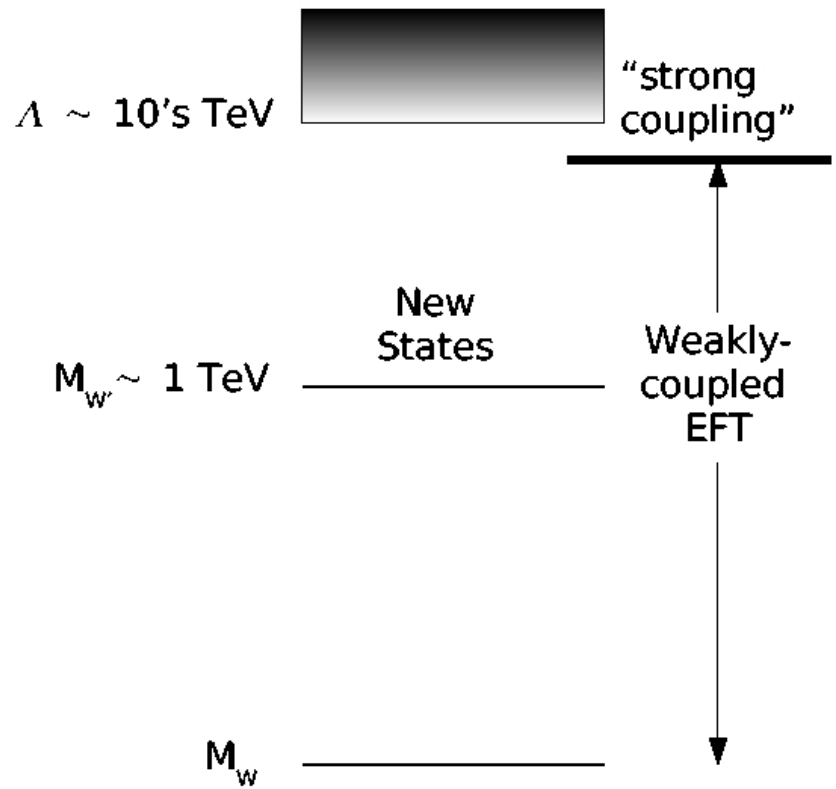
Hierarchy: $M_W^2 \ll M_{W'}^2 \ll \Lambda^2$

Chiral logs: identify poles w/ appropriate logarithmic divergences

$$\frac{1}{\epsilon} \rightarrow \log \frac{\Lambda^2}{M^2}$$

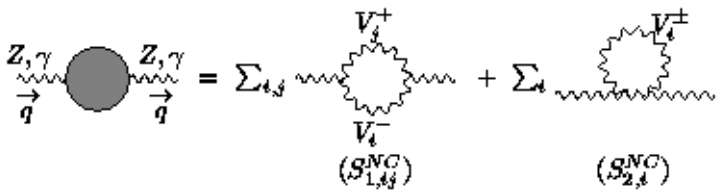
All diagrams calculated using generic couplings and Feynman rules

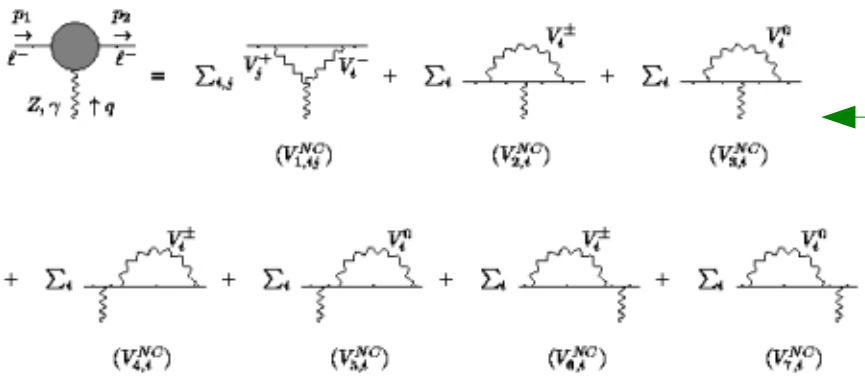
Easily coded into Mathematica, Maple, Fortran, etc.



Bloody Detail

Two-point Functions

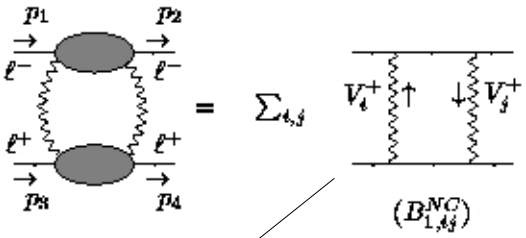




Vertex Diagrams

(and some external leg corrections)

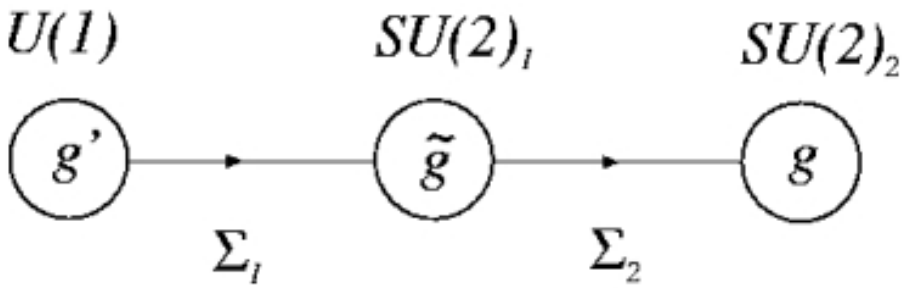
Box Diagrams



For example:

$$\left\{B^{NC}_{1,ij}\right\} = \frac{g^2_{l\nu V_i} g^2_{l\nu V_j}}{M_i^2 M_j^2}\left[B_{22}(q^2; M_i, M_j) - (M_i^2 + M_j^2) B_0(q^2; M_i, M_j)\right]$$

The Three Site Model (3SM)



(Foadi et al., hep-ph/0312324; Perelstein hep-ph/0408072; Chivukula et al. hep-ph/0607124)

Gauge Sector ≡ "BESS" Model (Casalbuoni et al. Phys. Lett. 155B: 95, 1985)

Spectrum = SM-like (γ, *W*, *Z*) *plus* **heavy triplet** (*W′* and *Z′*)

Exchange free parameters: $\{g, g', \tilde{g}, f_1, f_2\} \rightarrow \{e, M_W, M_Z, M_{W'}, M_{Z'}\}$

Fermion Delocalization:

$$S_{tree} = \frac{4 s_W^2 M_W^2}{M_{W'}^2}\left(1 - \frac{x_1 M_{W'}^2}{2 M_W^2}\right)$$

One-loop corrections to *S* and *T* first calculated by **Chivukula et al.** (hep-ph/0607191, 0702218) **neglecting terms of order x^2.**

3SM @ One Loop

One loop corrections to *X* (*X* = *S* or *T*):

$$X = X_{tree} + A_W^X \log\frac{\Lambda^2}{M_W^2} + A_{W'}^X \log\frac{\Lambda^2}{M_{W'}^2} + X_0$$

$$= X_{tree} + A_W^X \log\frac{M_{W'}^2}{M_W^2} + (A_W^X + A_{W'}^X)\log\frac{\Lambda^2}{M_{W'}^2} + X_0$$

"Low-energy" (or SM) piece

"High-energy" piece

Higher-d Operators

"Low-energy" pieces → diagrams with only light (SM) particles

"High-energy" pieces → diagrams with at least one heavy (*W'*, *Z'*) particle

"Higher-d" operators → parameterize physics above Λ (act as CT's)

Matching to the SM

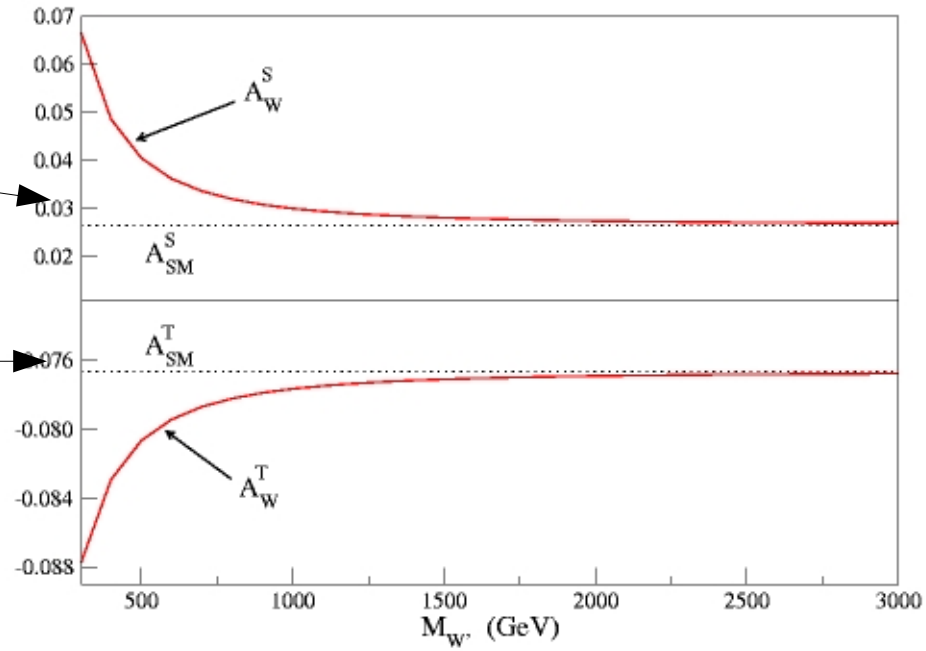
Well below $M_{W'}$: symmetries/operators of 3SM = SM with a **heavy Higgs**

Important check: low-energy coefficients **reduce to SM values**???

Heavy Higgs values:

$$A^S_{SM} = \frac{1}{12\pi}$$

$$A^T_{SM} = -\frac{3}{16\pi c_W^2}$$



To leading-log approximation:

$$A^S_W \simeq \frac{1}{12\pi}\log\frac{M^2_{W'}}{M^2_W} \longleftrightarrow A^S_{Higgs} \simeq \frac{1}{12\pi}\log\frac{M^2_H}{M^2_W}$$

Role of Higgs being played by W'

T vs. Mass Difference

In 3SM, **tree-level contribution to *T* vanishes** (custodial symmetry)

For delocalized fermions: *T* receives **sizable (and positive)** contributions from **heavy partners of the top and bottom quarks.**

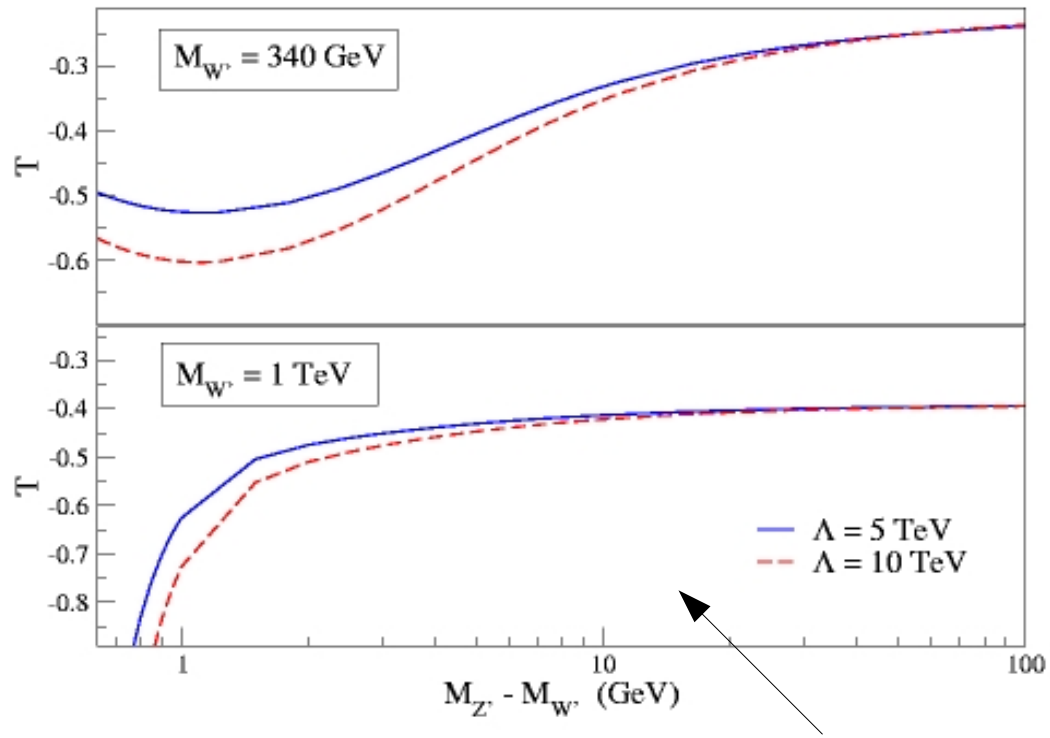
Limits on *T* (PDG 2006):

$$-0.15 \leq T \leq 0.27$$

($M_{W'} = M_H = 340$ GeV)

$$0.02 \leq T \leq 0.42$$

($M_{W'} = M_H = 1$ TeV)

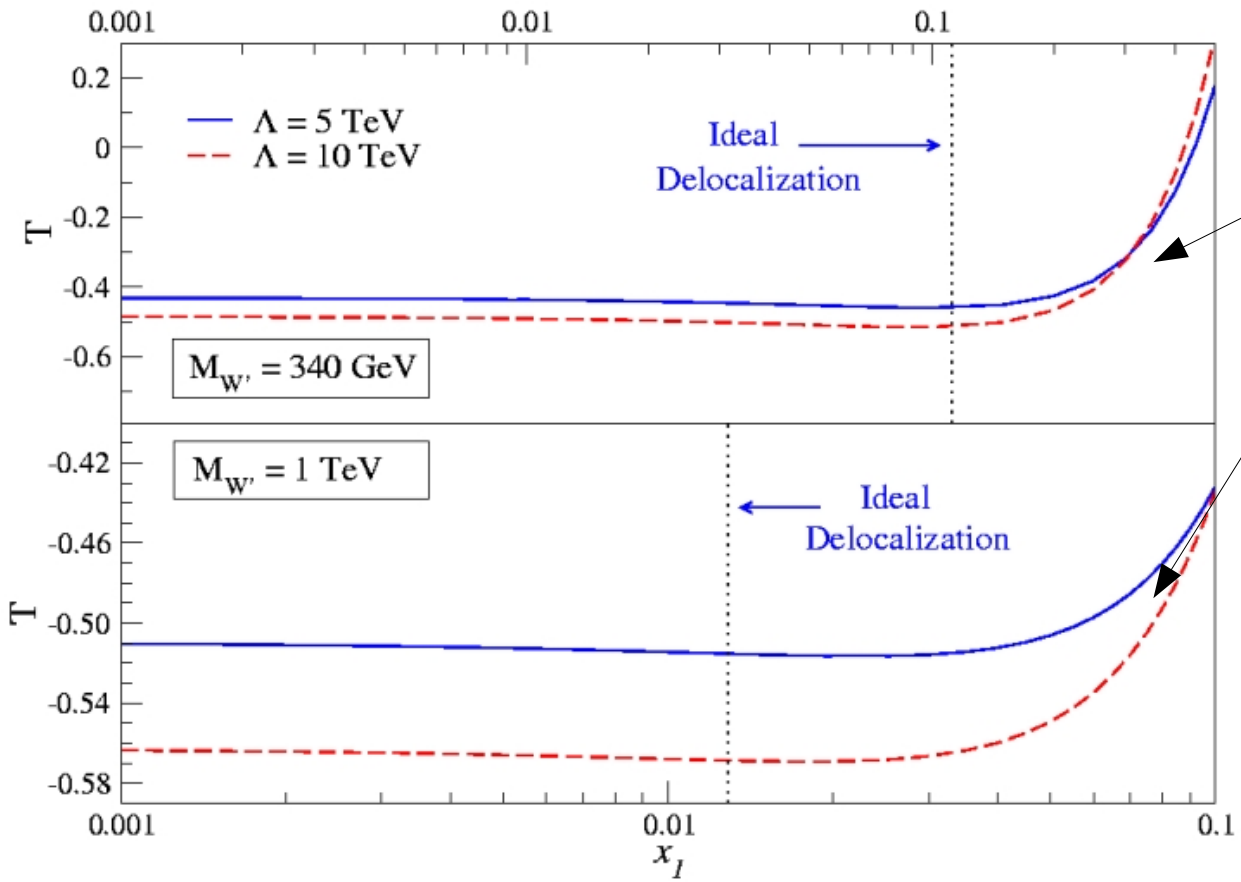


Large cancellation between heavy fermions and gauge bosons???

ID fermions

T vs. Delocalization Parameter

Delocalization process respects custodial symmetry:
x_1 dependence should be small (Chivukula et al., PRD74, 075011 (2006)).



Constraints on *ZWW* vertex rule out "large" values of x_1

***T* parameter independent of delocalization procedure (even @ one loop)**

S vs. Mass Difference

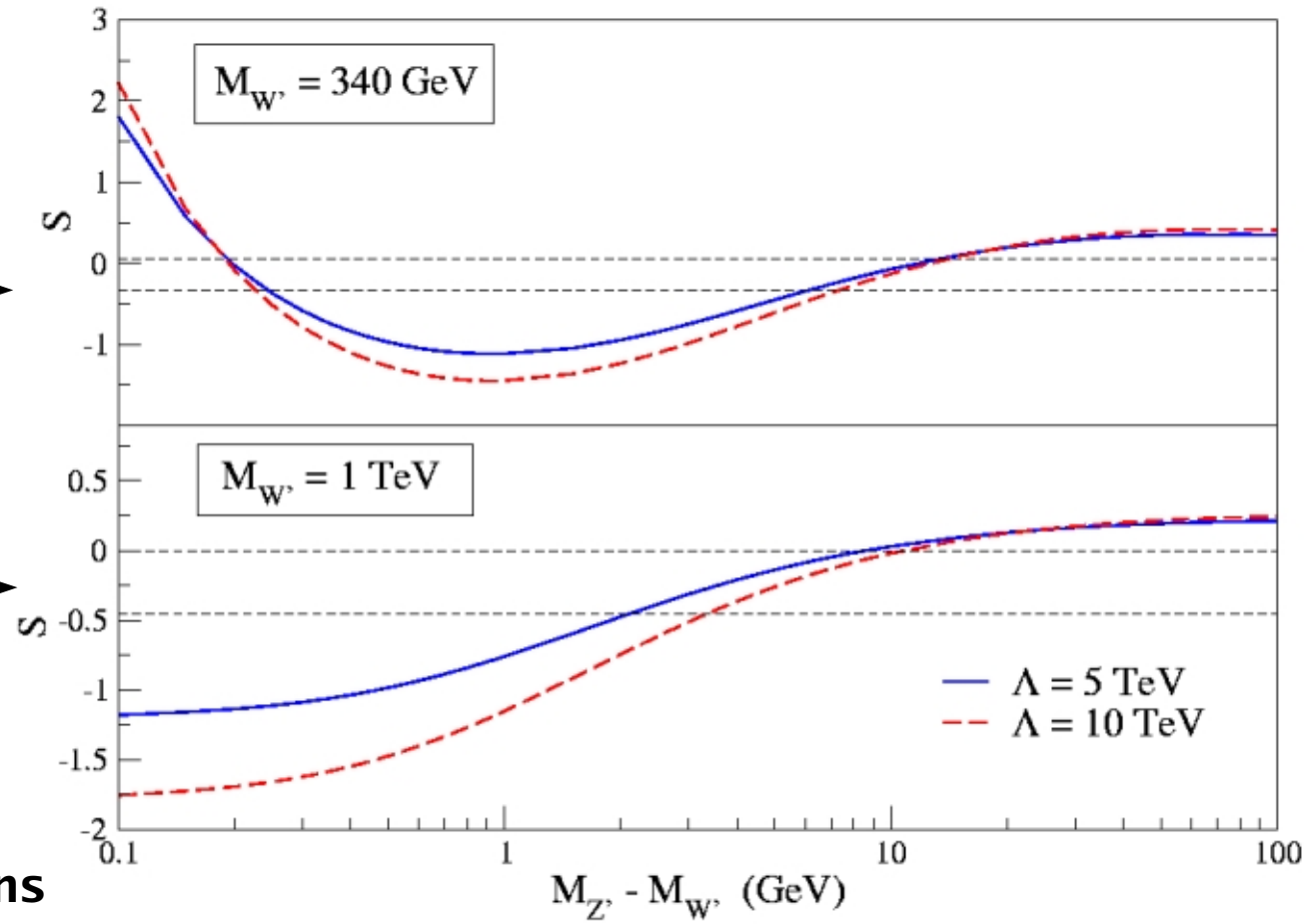
Compare to exp. Limits with identical Higgs mass (PDG 2006):

$$-0.33 \leq S \leq 0.05$$

($M_{W'} = M_H = 340$ GeV)

$$-0.45 \leq S \leq 0.00$$

($M_{W'} = M_H = 1$ TeV)



Ideally delocalized fermions ($S_{tree} = 0$)

One-loop, chiral-log corrections can be large...i.e., *O* (±1).

Only small "windows" in mass difference where *S* agrees with exp. data

S vs. Delocalization Parameter

Important issue regarding delocalizing fermions:

1) "Ideal" value is ideal at all orders or...

2) Loop corrections are large s.t. x_1 must be **"re-tuned" order-by-order**

For "lighter" W′:

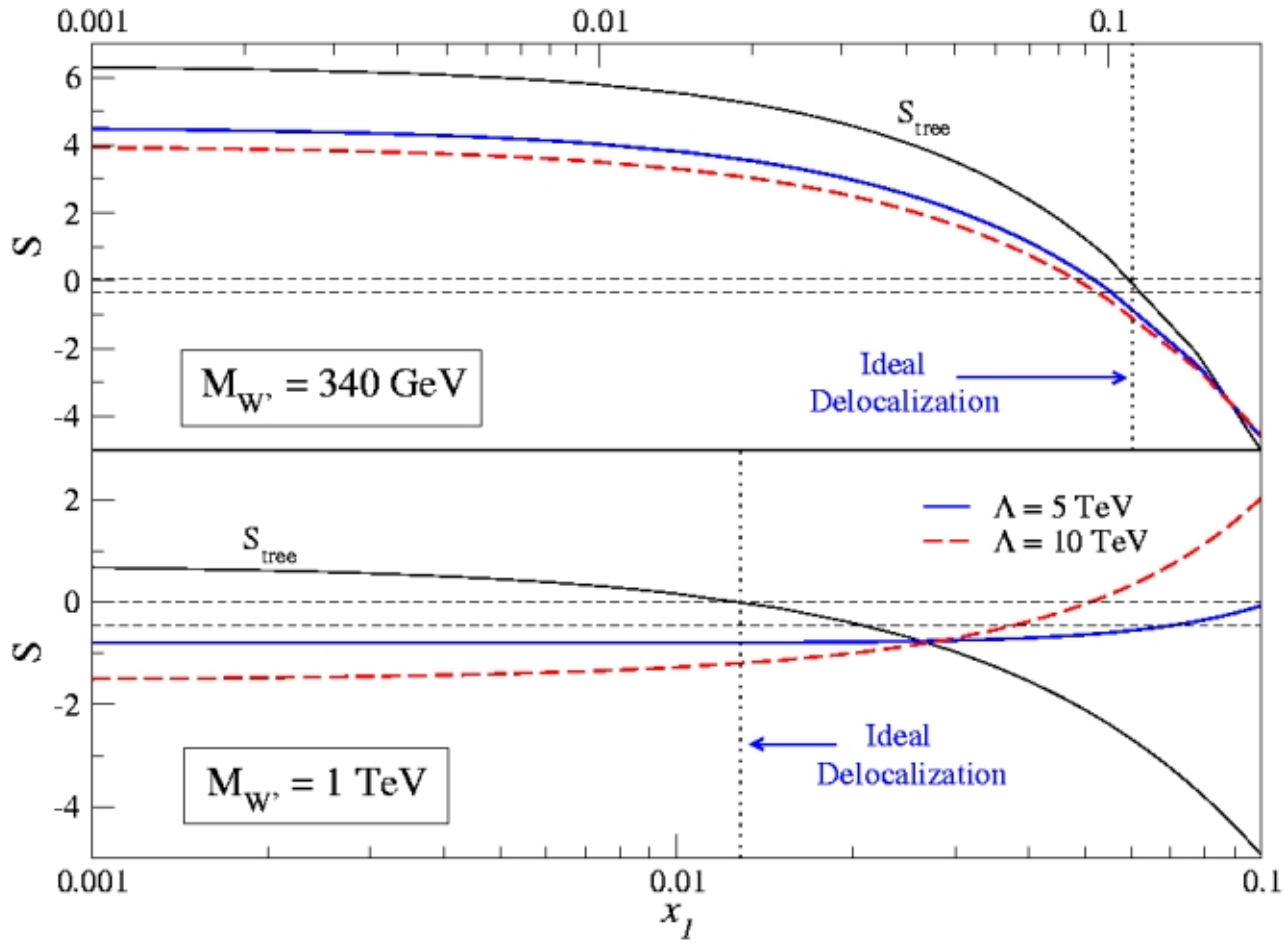
S_{tree} dominates...

re-tuning is small (20-30%)

For "heavier" W′:

One-loop corrections comparable to S_{tree}...

re-tuning needed is large (factor of ~5)



Conclusions

Constructed a **"recipe"** for calculating **one-loop corrections to *S* and *T*** parameters in ~~**Higgs**~~ **models**

Algorithm could be used to calculate gauge sector contributions in models **with fundamental (or composite) Higgs bosons**

Novel application of Pinch Technique

Easily coded into Mathematica, Maple, etc.

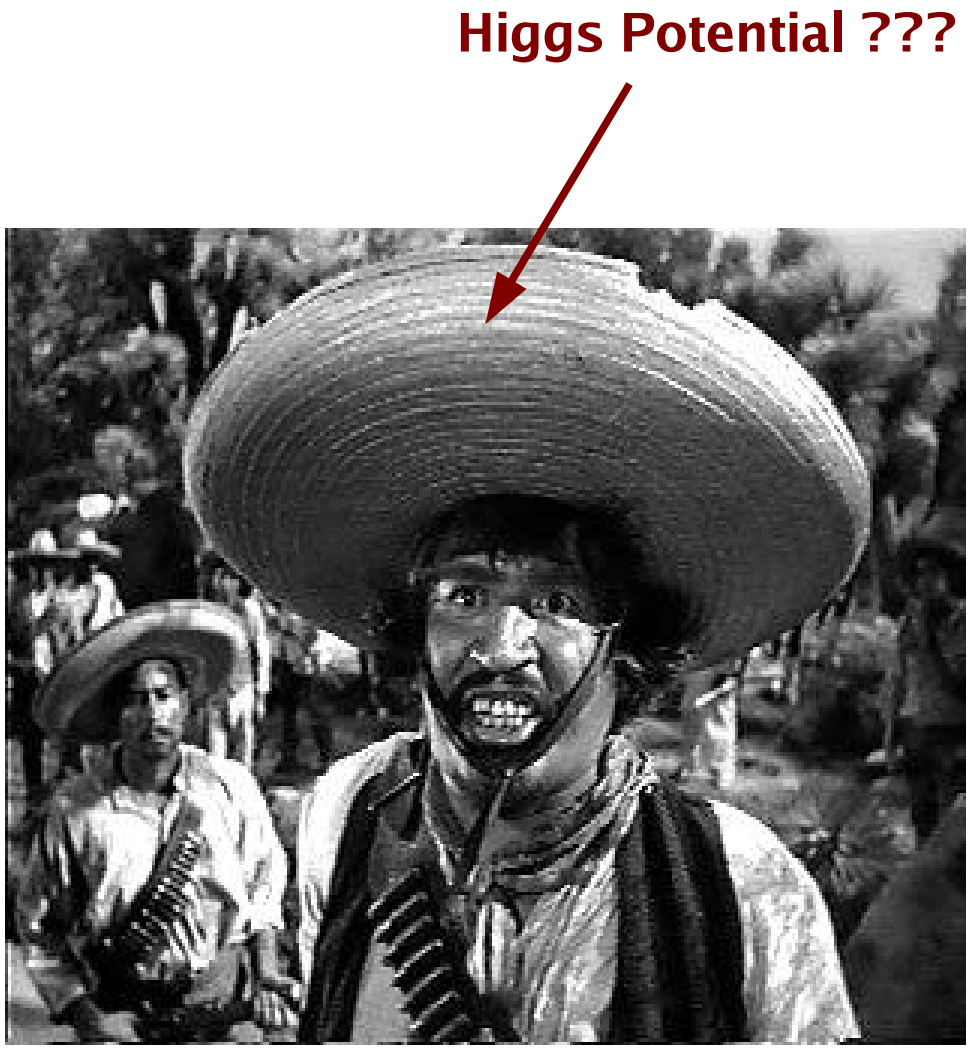
<u>Application to Three Site Model:</u>

***T* parameter**: sizable (and negative) contributions which cancel against **fermionic contributions (?)**

***S* parameter:** 1) chiral log's can be **large**
2) only **small regions** in $M_{Z'}$ - $M_{W'}$ allowed
3) for heavy W', **large "re-tuning"** needed

And, finally...

Final Conclusion

“Higgs?!?
We don’t need
no stinkin’
Higgs!”

--Gold Hat, *The Treasure of the Sierra Madre (1948)*