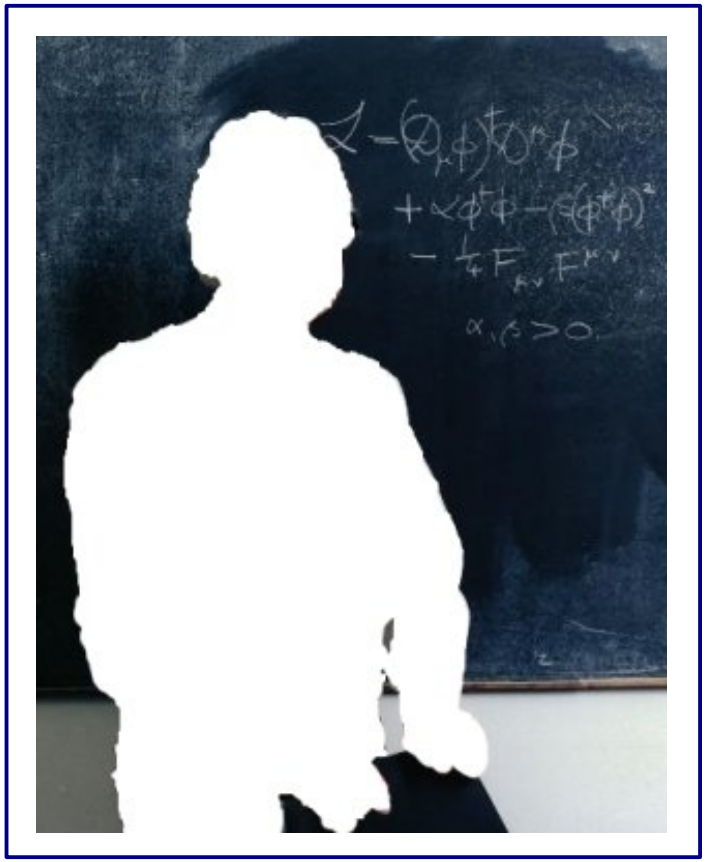
S and *T* @ One-loop in ~~Higgs~~ Models

C.B. Jackson (w/ S. Dawson), BNL

(Based on hep-ph/0703299)

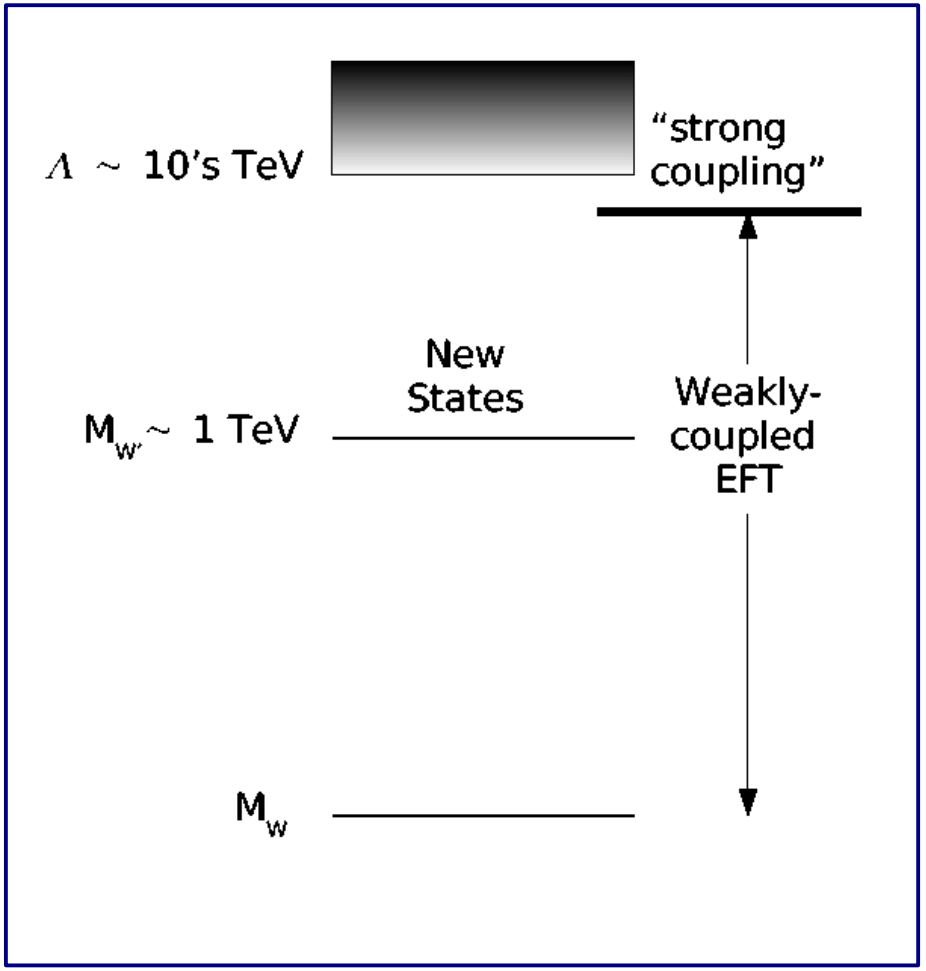


- The Model(s)
  - Three site model (3SM)
- "Generic" Recipe
  - Pinch Technique (PT)
- Results for 3SM
  - "Localized" fermions
  - Ideally-delocalized fermions

The Model(s)

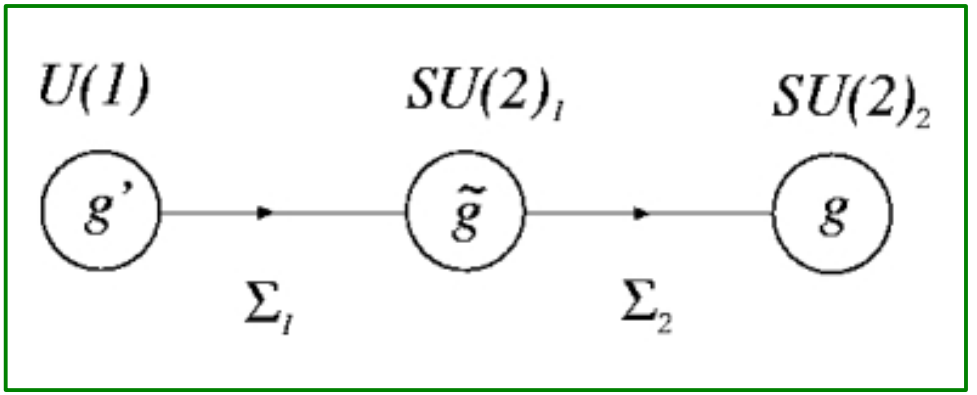
- **Higgless Model(s):**
  - Extra-dimensional: BCs → EWSB
  - Deconstructed: $SU(2)\times SU(2)^N\times U(1)$
- **Related Features:**
  - SM plus "towers" of W's and Z's
  - Non-renormalizable: EFT's up to Λ
  - Three Scales:

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



The Three Site Model (3SM)...again.

- **Prototypical example**:
  - ✔ Spectrum = SM plus (W', Z')
  - ✔ EFT valid up to Λ (~ 5-10 TeV)
  - ✔ Scales: $M_W^2 \ll M_{W'}^2 \ll \Lambda^2$



- **Different Approach** (Foadi et al., JHEP 0403:042, 2004):
  - Free parameters:

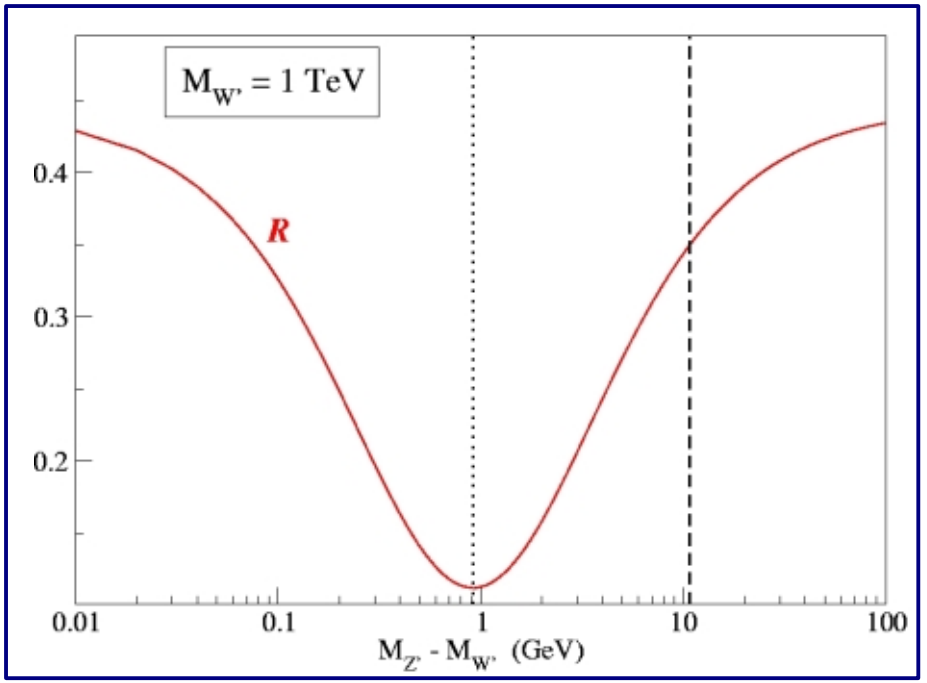
    $\{g, g', \tilde{g}, f_1, f_2\} \rightarrow \{e, M_W, M_Z, M_{W'}, M_{Z'}\}$

  - Couplings between mass eigenstates = $f(M_W, M_{Z'})$
  - Delocalization parameter = x_1

e.g.

$$g_{WWZ'} = g\, a_{22}^2 b_{21} + \tilde{g}\, a_{12}^2 b_{11}$$

Making the Connection



- $W_L W_L \to W_L W_L$ **Scattering**:

$$A = \frac{E^2}{M_W^2}\frac{(1+\cos\theta)}{2}R + O\left(\frac{M_W^2}{E^2}\right)$$

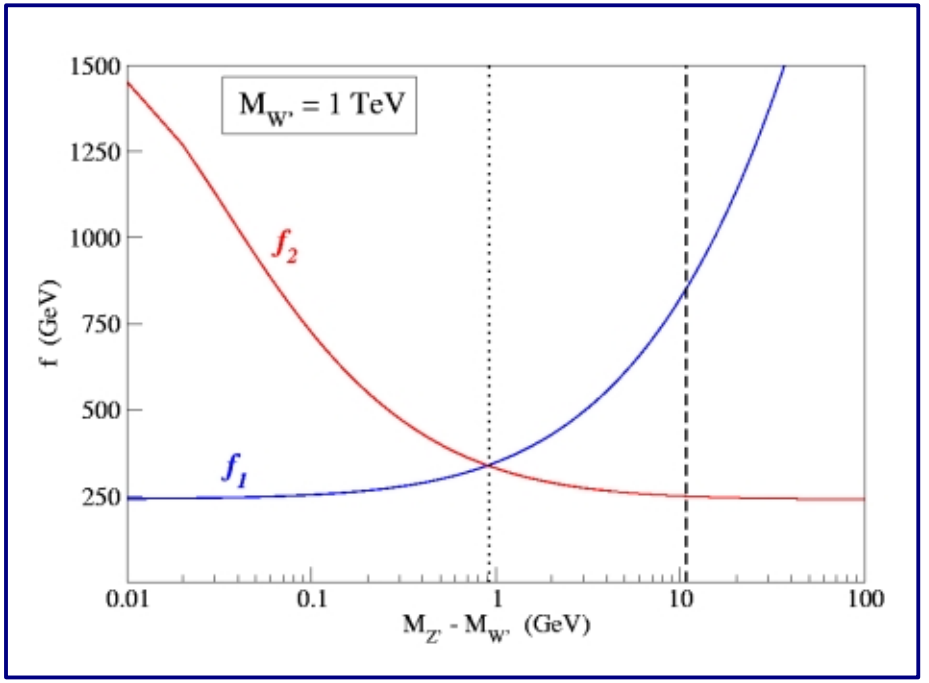
$$R \equiv 4\,g_{WWWW} - 3\left[g_{WWZ}^2\frac{M_Z^2}{M_W^2} + g_{WWZ'}^2\frac{M_{Z'}^2}{M_W^2}\right]$$

- Maximal suppression at:

$$M_{Z'}^2 - M_{W'}^2 = M_Z^2 - M_W^2$$

- "Starting point" for Chivukula et al. (PRD74: 0705011, 2006, etc.)

$$f_1 = f_2 \quad \to \quad (g, g') \approx (g_{SM}, g_{SM}')$$



The Pinch Technique

- **Oblique parameters**:

$$\frac{\alpha S}{4 s_W^2 c_W^2} = \Pi'_{ZZ}(0) - \Pi'_{\gamma\gamma}(0) - \frac{c_W^2 - s_W^2}{s_W c_W}\Pi'_{\gamma Z}(0)$$

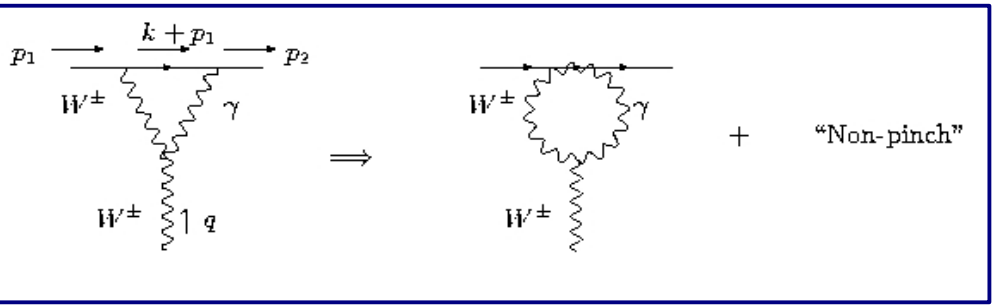
$$\alpha T = \frac{\Pi_{WW}(0)}{M_W^2} - \frac{\Pi_{ZZ}(0)}{M_Z^2}$$

- **Gauge-boson loops** → $\Pi_{ij}(q^2) = \Pi_{ij}(q^2)\big|_{\xi=1} + f_{ij}\left(\xi, q^2, M_i^2\right)$

- **Pinch Techinque (PT)**:

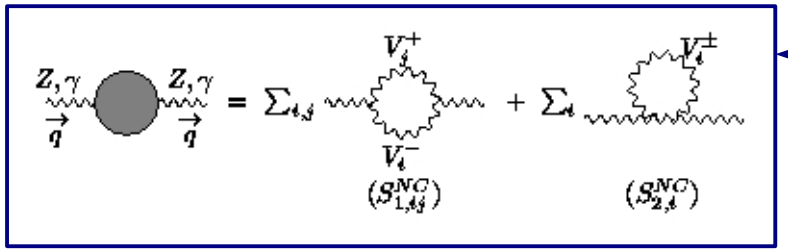
Gauge-independent ***Individually*** **gauge-dependent**

– Systematically isolate "propagator-like" corrections from vertex/box diagrams:



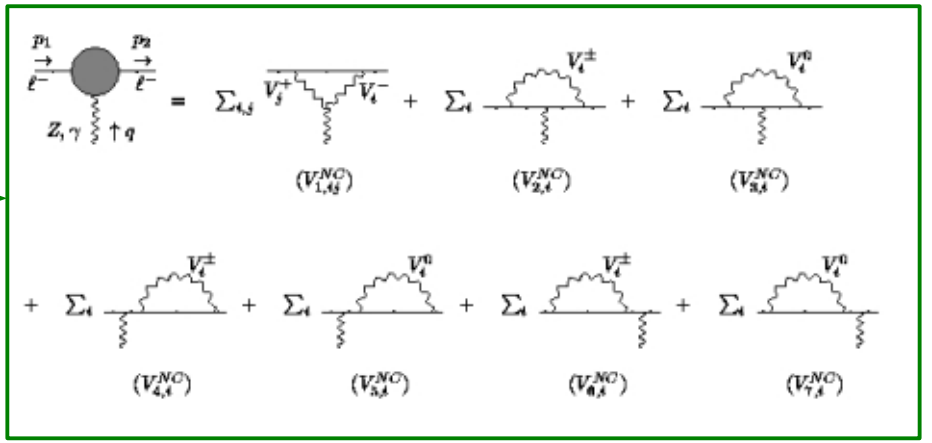
Application to a Generic ~~Higgs~~ Model

- **Objective**: "recipe" for calculating S and T @ one-loop in ~~Higgs~~ models
- **Starting points**:
  - Spectrum = SM gauge sector *plus* (at least) one set (W', Z')
  - Mass hierarchy: $M_W^2 \ll M_{W'}^2 \ll \Lambda^2$ (identify poles w/ chiral logs)
  - Unitary gauge ($\xi \to \infty$) to minimize number of diagrams
- All diagrams calculated using **"generic" couplings/Feynman rules**:



Two-point Functions

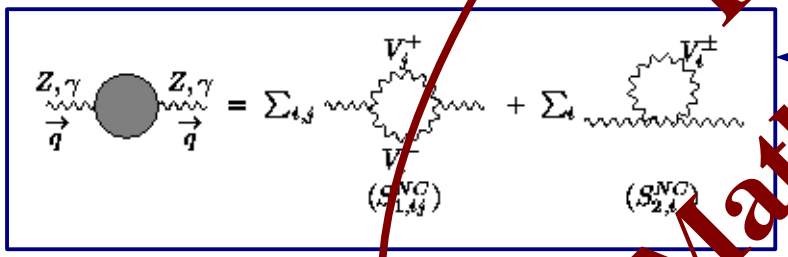
Vertex Corrections (and some external leg corrections)



Application to a Generic ~~Higgs~~ Model

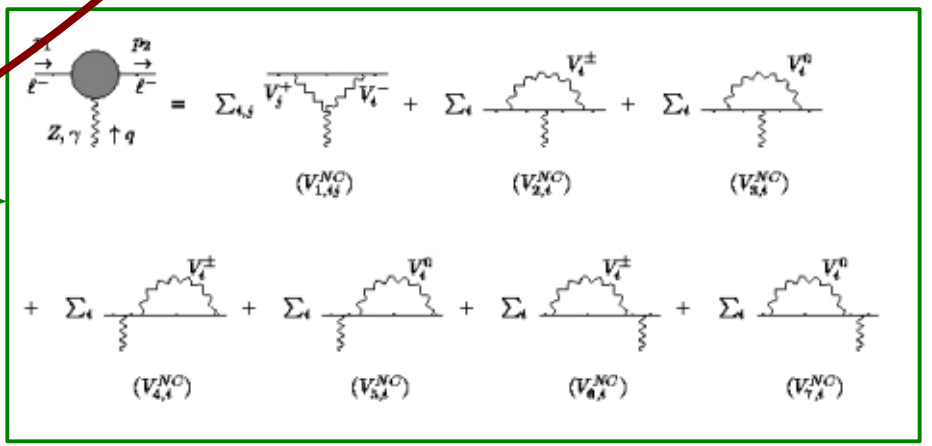
- **Objective**: "recipe" for calculating *S* and *T* @ one-loop in ~~Higgs~~ models
- **Starting points**:
  - Spectrum = SM gauge sector *plus* (at least) one set (W', Z')
  - Mass hierarchy: $M_W^2 \ll M_{W'}^2 \ll \Lambda^2$ (identify poles w/ chiral logs)
  - Unitary gauge ($\xi \to \infty$) to minimize number of diagrams
- All diagrams calculated using **"generic" couplings/Feynman rules**:

Easily code into Mathematica, Maple, etc.



Two-point Functions

Vertex Corrections (and some external leg corrections)



S and T in the 3SM

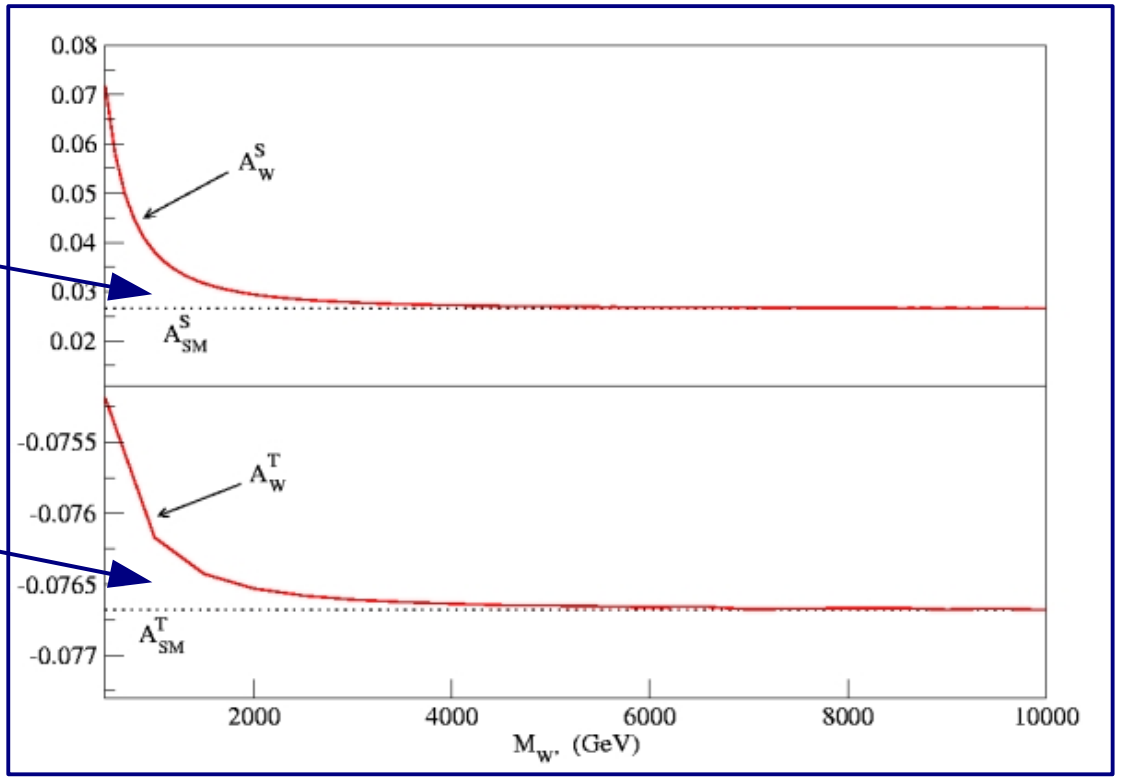
- **One-loop corrections** to X ($X = S$ or T) **naturally separate**:

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

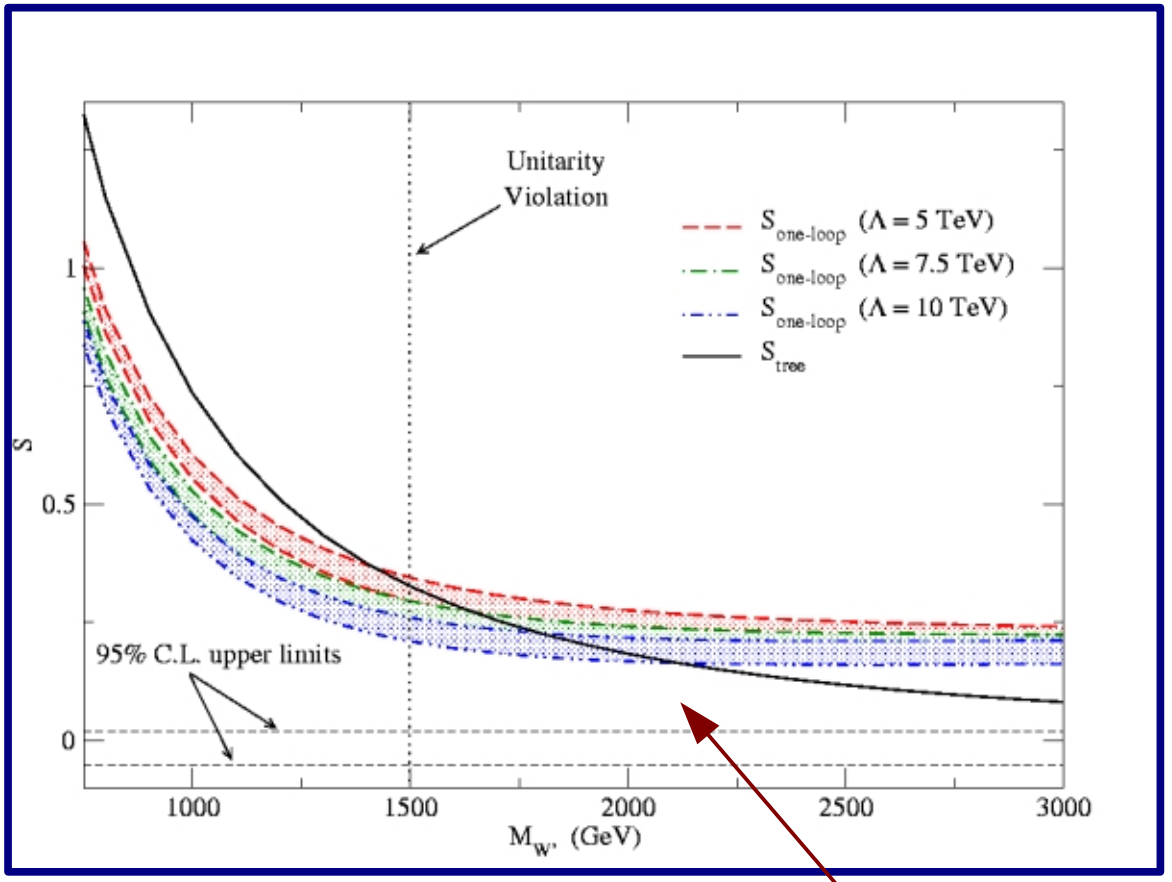
- **First check**: low-energy coefficient(s) = SM (w/ heavy Higgs) values???

$$A_{SM}^S = \frac{1}{12\pi}$$

$$A_{SM}^T = -\frac{3}{16\pi c_W^2}$$



S @ One-loop in the 3SM



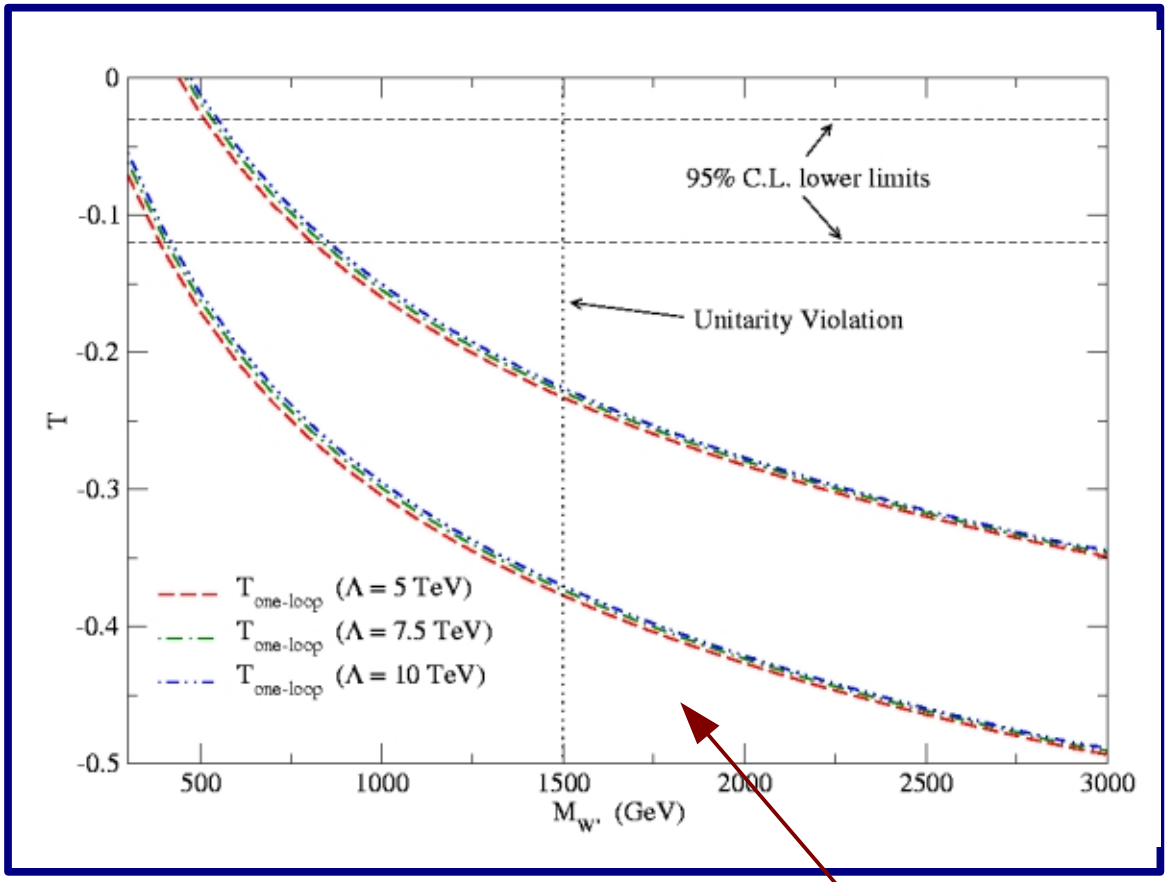
- **"Localized" fermions**
  - **Dominated** by S_{tree}
- Two reference Higgs masses
- Chiral logs **reduce total**

  ...but, probably not enough
- **"Tension"**:

  Unitarity constraints vs. S

$$M_{Z'} - M_{W'} = M_Z - M_W$$

T @ One-loop in the 3SM



- **"Localized" fermions**
  - $T_{tree} = 0$ (custodial symmetry)
- T **consistent** with Unitarity
- **Independence** of cutoff scale:

$$A_W^T + A_{W'}^T \simeq 0$$

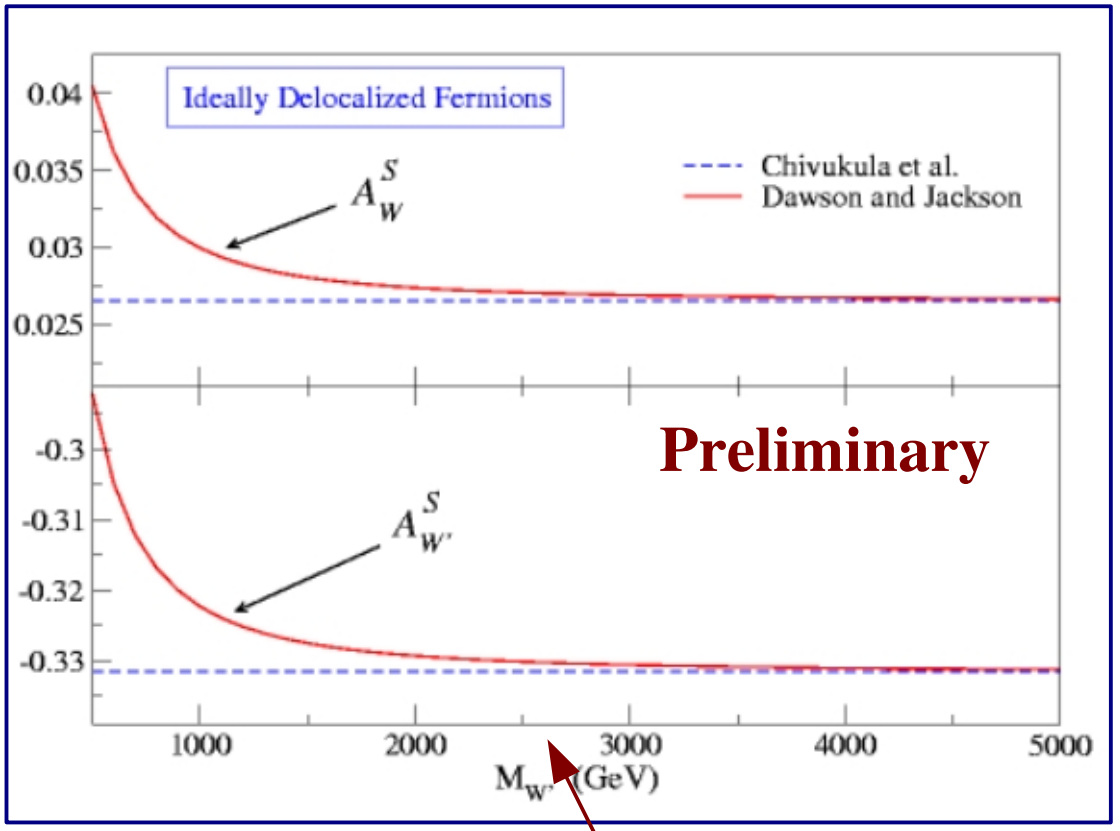
Custodial Symmetry at Work!(?)

$$M_{Z'} - M_{W'} = M_Z - M_W$$

S @ One-loop w/ Delocalized Fermions

- **Compare w/ results of Chivukula et al.:**
  - PRD75: 073002, 2007
  - hep-ph/0702218

- **Ideally Delocalized** Fermions
  - Tree-level *S* vanishes

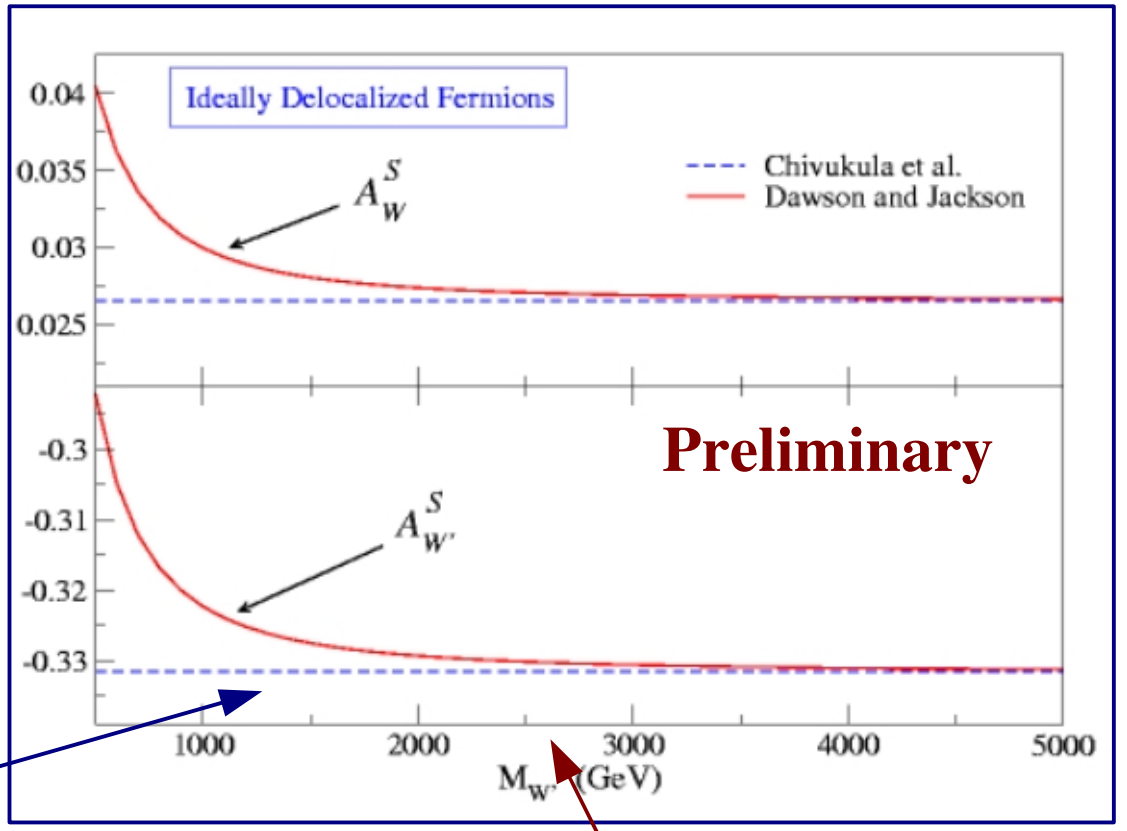


$$M_{Z'}^2 - M_{W'}^2 = M_Z^2 - M_W^2$$

S @ One-loop w/ Delocalized Fermions

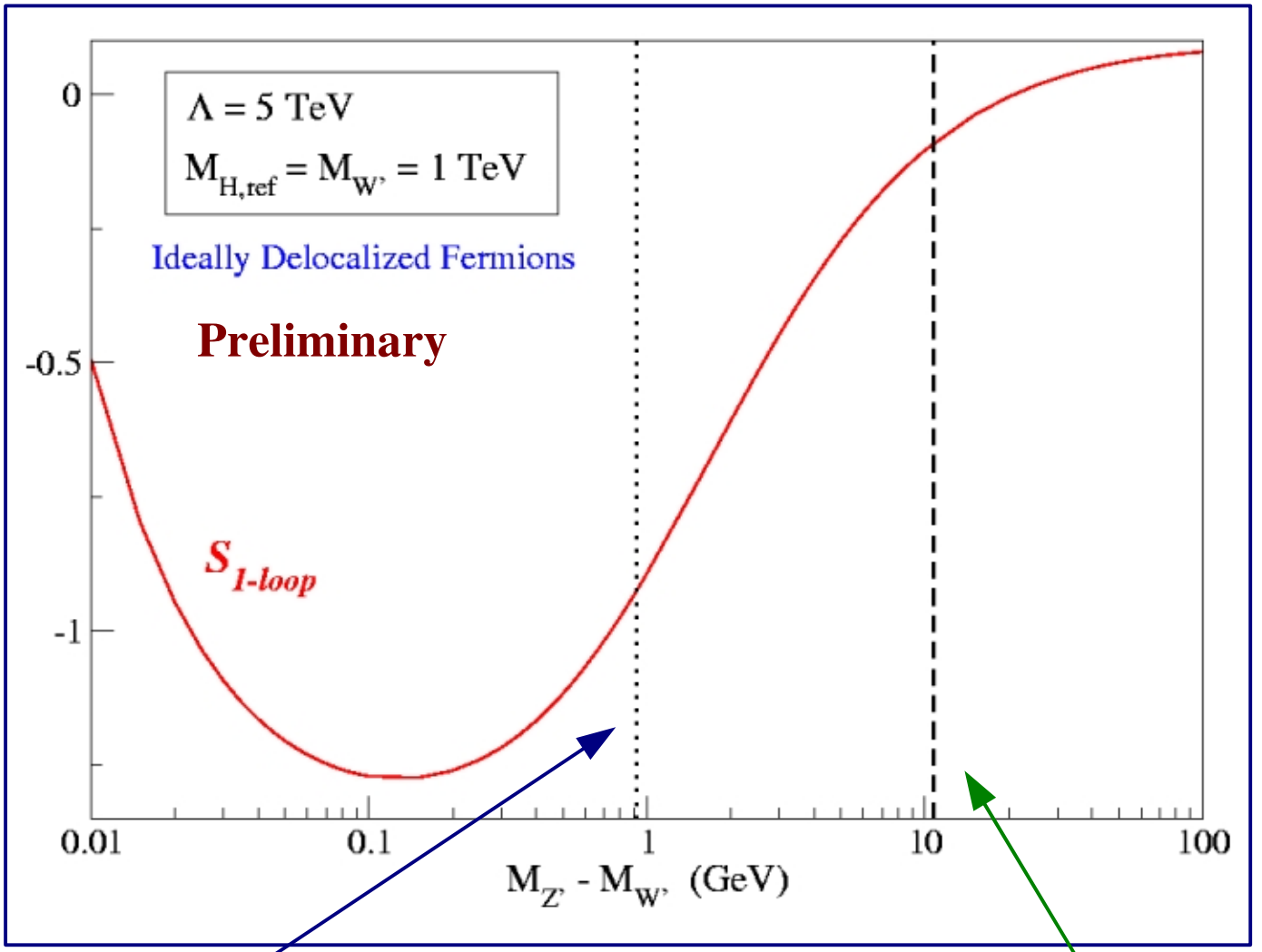
- **Compare w/ results of Chivukula et al.:**
  - PRD75: 073002, 2007
  - hep-ph/0702218

- **Ideally Delocalized** Fermions
  - Tree-level *S* vanishes



$$M_{Z'}^2 - M_{W'}^2 = M_Z^2 - M_W^2$$

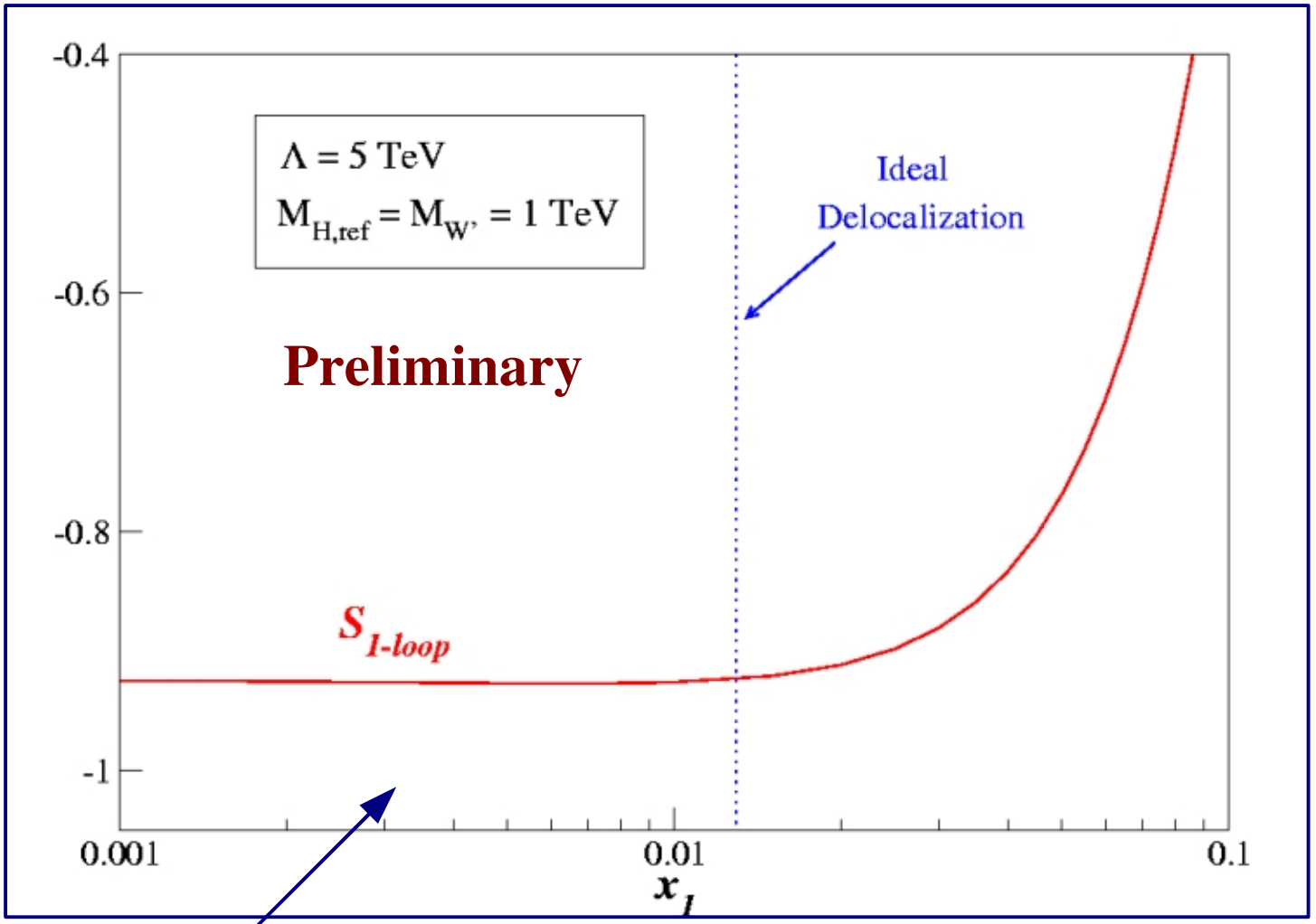
Mass-difference Dependence of *S*



$$M_{Z'}^2 - M_{W'}^2 = M_Z^2 - M_W^2$$

$$M_{Z'} - M_{W'} = M_Z - M_W$$

Dependence on Delocalization Parameter



$$M^2_{Z'} - M^2_{W'} = M^2_Z - M^2_W$$

Conclusions

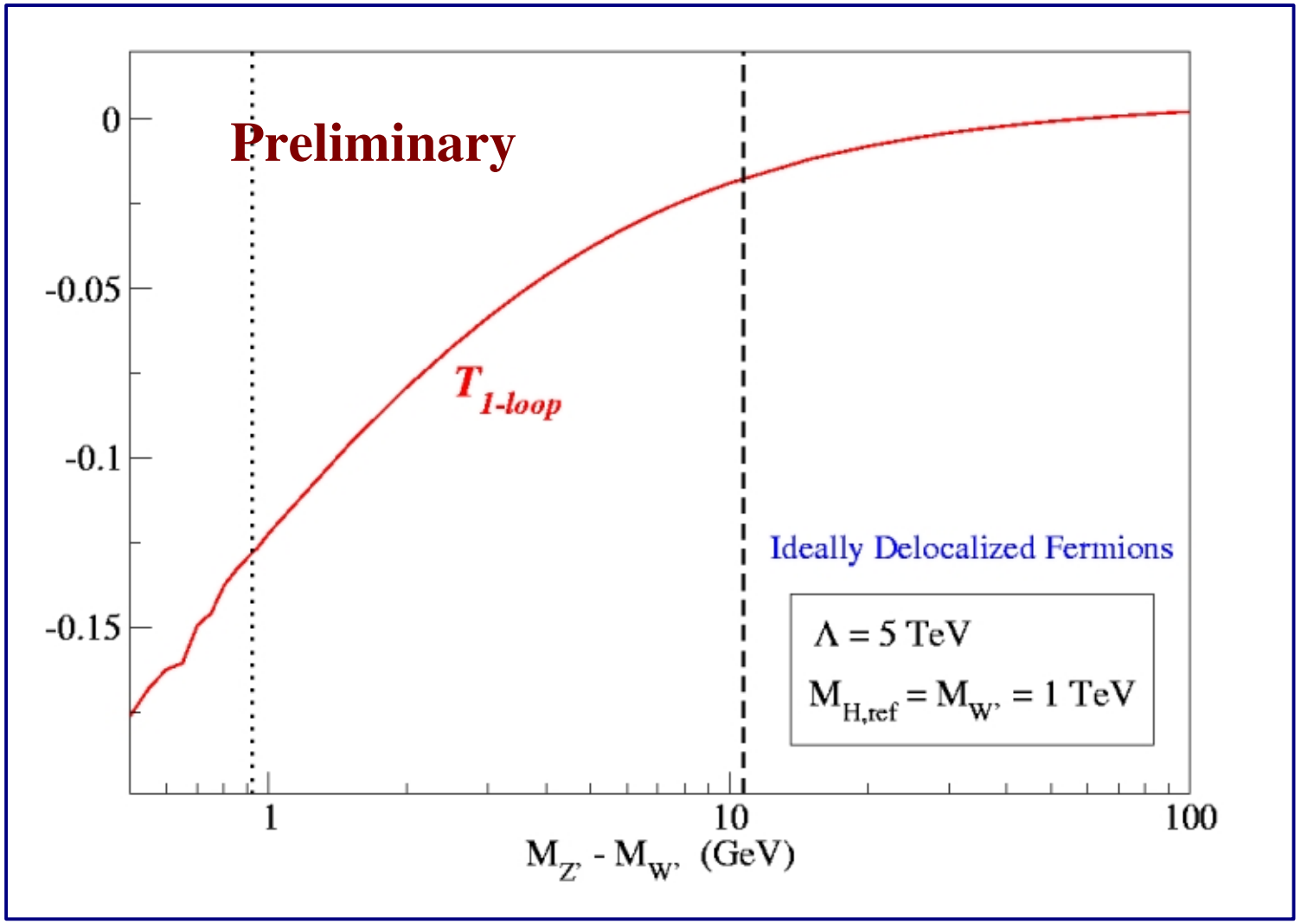
- Constructed a **"recipe"** for calculating **one-loop corrections** to *S* and *T* parameters in ~~**Higgs**~~ **Models**
  - Novel application of Pinch Technique
- Application to the **Three Site Model**
  - **Localized fermions:**
    - *S* parameter still dominated by tree-level
    - *T* parameter remains small (custodial symmetry?)
  - **Delocalized fermions:**
    - Beautiful agreement w/ results from Chivukula et al. (**gauge-independent!**)
    - Behavior of *S* w.r.t. mass differences and delocalization parameter
- **Lots of exciting aspects of the 3SM yet to investigate!** (see, e.g., talks by Liz, Neil and Sasha)...

...some parting words

"Higgs?!?
We don't need
no stinkin'
Higgs!"

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

Backup Slide: *T* vs. Mass Difference



Backup Slide: Pieces of *S* vs. Delocalization