T-Parity in Fermionic UV Completions of Little Higgs Models

David Krohn, based on work with Itay Yavin (arXiv:0803.4202 [hep-ph])

Motivation

- Little Higgs theories are models created to solve the little hierarchy problem.

- They take particular symmetry breaking patterns and identify some of the Goldstones of these with the Higgs.

- The low energy description of some of these models has a parity (T-parity, analogous to the R-parity of SUSY), which is important in model building. It helps models evade electroweak constraints *and ensures a stable dark matter candidate*.

- Last year, Hill and Hill [a] [b] showed that quantum anomalies are important in discussing little Higgs model building.
- Quantum anomalies come from fermions. Anomalies from fermions in the UV description of a theory manifest themselves at low energies in WZW terms.
- The $\pi \to \gamma\gamma$ interaction from QCD is the result of one such anomaly. It is the result of anomalies in the global $\mathrm{SU}(3)_L \times \mathrm{SU}(3)_R$ symmetry of the quarks.

[a] C. T. Hill and R. J. Hill, *T-Parity Violation by Anomalies*, Phys. Rev. D76 (2007) 115014, [arXiv:0705.0697 [hep-ph]]

[b] C. T. Hill and R. J. Hill, *Topological Physics of Little Higgs Bosons*, Phys. Rev. D75 (2007) 115009, [hep-ph/0701044]

- WZW terms can violate T-parity. Again, this is analogous to QCD where the chiral Lagrangian has a symmetry $\pi \to -\pi$ that is broken by interactions like $\pi \to \gamma\gamma$.
- Although this does not hurt electroweak constraints, it renders any dark matter candidate unstable.
- *We want to know how generically T-parity is broken in little Higgs theories by these anomalies.*

Removing the WZW terms

- If WZW terms could be removed altogether there would be no problem with T-parity.

- One way to do this is to employ a linear UV completion with fundamental scalars. Stabilizing the electroweak scale requires that these scalars carry additional SUSY structure. This approach is taken in Csaki et al. [a]

- Another way to remove WZW terms is to build a model with anomaly free global symmetry groups.

[a] C. Csaki, J. Heinonen, M. Perelstein, and C. Spethmann, *A Weakly Coupled Ultraviolet Completion of the Littlest Higgs with T-Parity*, 0804.0622

UV completions of anomaly free models

- Little Higgs models based on anomaly free groups (SO and Sp) have been constructed [a] [b] [c].
- Is it possible to UV complete such a theory with condensing fermions?

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[a] S. Chang and J. G. Wacker, *Little Higgs and custodial SU(2)*, Phys. Rev. D69 (2004) 035002, [hep-ph/0303001].

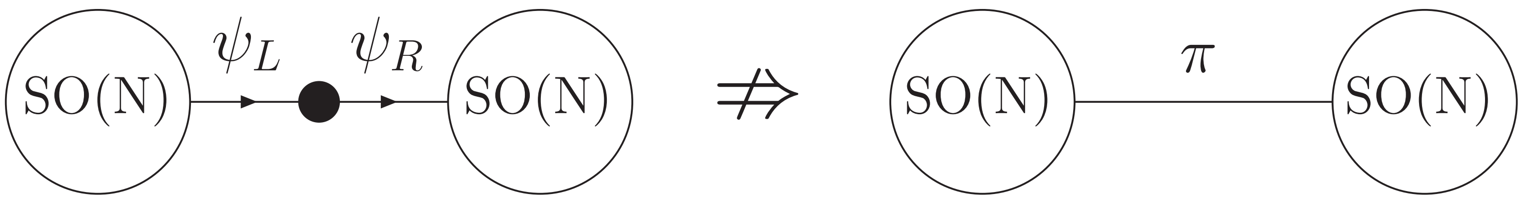
[b] H.-C. Cheng, J. Thaler, and L.-T. Wang, *Little M-theory*, JHEP 09 (2006) 003, [hep-ph/0607205].

[c] P. Batra and Z. Chacko, *Symmetry Breaking Patterns for the Little Higgs from Strong Dynamics*, arXiv:0710.0333 [hep-ph].

- Let's see what happens with a $\mathrm{SO}(N)\times\mathrm{SO}(N)/\,\mathrm{SO}(N)$ model. Our results can be generalized to other coset spaces.

- Begin by noting that a generic UV model with fermions will have $\mathrm{SU}(N)\times\mathrm{SU}(N)$ symmetry, which must be explicitly broken to $\mathrm{SO}(N)\times\mathrm{SO}(N)$.

- One way to get the right global symmetry is to introduce Majorana masses. These will yield the desired global symmetry.
- Unfortunately, Majorana masses will prevent the vacuum from realizing the desired symmetry breaking pattern.



Instead, we will only see $\mathrm{SU}(N) \times \mathrm{SU}(N) \to \mathrm{SO}(N) \times \mathrm{SO}(N)$

- This is because of the *persistent mass conjecture*: if the symmetry breaking pattern were $\mathrm{SO}(N) \times \mathrm{SO}(N) \to \mathrm{SO}(N)$ we would expect massless Goldstones made out of very heavy fermions. This is a contradiction, and it tells us that the vacuum will not break symmetry in this way.

- Since Majorana masses don't seem to work, we can look to higher dimensional operators to help achieve the desired symmetry breaking pattern.

- Dimension-six operators can reduce the global symmetry to $\mathrm{SO}(N) \times \mathrm{SO}(N)$:

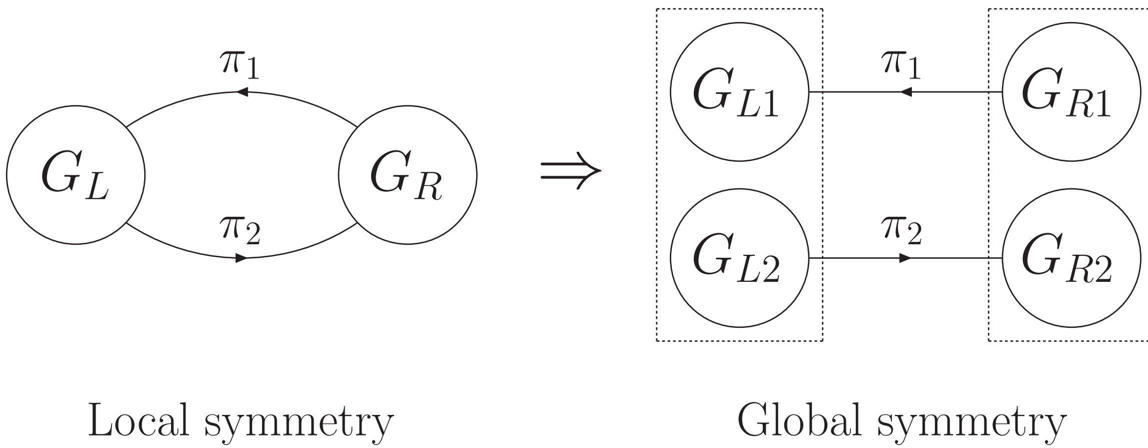
$$\mathcal{L} \supset \frac{y^2}{M^2} \psi_L^T \psi_L \bar{\psi}_L^T \bar{\psi}_L \quad + \quad L \to R$$

  However, they must have unnaturally large coefficients.

- Any trick that could naturally generate these operators without inducing a large fermion mass term would be an important tool for constructing little Higgs theories. We know of no realistic implementation to achieve this.

Multi-link moose models

- Many little Higgs theories are built from moose models [a]. These take a symmetry breaking pattern and copy it multiple times, gauging some linear combination of global symmetries.
- The multi-link model can be made free of gauge anomalies. However, this is not true for global anomalies.



[a] N. Arkani-Hamed et al., *The minimal moose for a little Higgs*, JHEP 08 (2002) 021, [hep-ph/0206020]

- Multi-link moose models will always have WZW terms because these are the result of the theory's global symmetry.

- Let's see how T-parity acts on such a model. Consider the case of a $\mathrm{SU}(3) \times \mathrm{SU}(3)$ moose model with two sites. Label the link fields π_1 and π_2, and gauge the combination of the upper left $\mathrm{SU}(2)$ and the diagonal $\mathrm{U}(1)$. The Higgs lives in the Goldstone fields:

$$\pi \to \left(\begin{array}{c|c} d & h \\ \hline h^\dagger & d \end{array}\right)$$

  and we identify the combination $\pi_1 - \pi_2$ as that containing the SM Higgs.

- T-Parity is normally defined to take

$$U_{1/2} \to \Omega U_{1/2}^{\dagger}\Omega, \;\; A_{L/R} \to A_{R/L}$$

where

$$\Omega = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & -1 \end{pmatrix}$$

- Under this transformation the kinetic terms in the Lagrangian go into themselves. The WZW terms, however, go

$$\mathcal{L}_{\rm WZW}(\pi, A_L, A_R) \xrightarrow{T\text{-Parity}} -\mathcal{L}_{\rm WZW}(\pi, A_L, A_R)$$

- It looks like T-parity is broken. However, we can change the definition of T-parity to involve an interchange of the π fields. The new definition of T-parity takes

$$U_{1/2} \rightarrow \Omega U_{2/1} \Omega, \;\; A_{L/R} \rightarrow A_{R/L}$$

- This is an exact symmetry of both the kinetic and WZW terms of the theory. Therefore, the particles odd under this symmetry are stable against decay. They could be dark matter candidates.

- We hope to implement this symmetry in a more realistic model with SM fermions.

Conclusions

- Ordinary QCD-like models cannot UV complete little Higgs models based on anomaly free groups.
- Moose models, although anomalous, can be arranged to have an exact parity.