Philip 'Flip' Tanedo: **Research Statement**

Synopsis: weakly coupled composite naturalness

The recent discovery of what appears to be the Standard Model Higgs boson, combined with the absence of new physics at the Large Hadron Collider (LHC), constrains the form of any natural solution to the hierarchy problem. For example, within the paradigm of supersymmetry (SUSY), naturalness requires an unusual flavor-prejudiced spectrum with decoupled squarks except for relatively light stops. It is challenging to realize this type of spectrum in a UV model of new physics without, for example, running into problems from flavor bounds.

One promising framework that can do this is *partial compositeness* with the Higgs and top identified as composite states. These technicolor-type models were originally envisioned as an alternative to the Higgs, but have recently found novel uses as UV completions of the Higgs via the dualities discovered in the past two decades. My research has focused on weakly coupled descriptions of strongly coupled physics—warped extra dimensions, Seiberg duality, and effective nonlinear realizations—and their applications to models of new physics accessible to colliders, flavor factories, and dark matter experiments.

Warped penguins: flavor & loops in five dimensions

The Randall-Sundrum (RS) model of a warped extra dimension provides a holographic description of strongly coupled 4D gauge theories. In [1] we performed the first full calculation of a loop-induced 5D dipole operator using a manifestly 5D formalism. We explained the finiteness of these diagrams based on symmetries and showed that ambiguities in the standard Kaluza-Klein method originate from calculating loops in a way which breaks 5D Lorentz invariance. We later applied similar techniques to a model of top condensation in an extra dimension and showed that electroweak symmetry can be broken through a dynamically generated brane-localized potential [2].

The RS framework with bulk fields naturally explains the fermion mass hierarchy and even provides some protection against tree-level flavor-changing neutral currents. Loop-level flavor observables, however, have a different dependence on the 5D parameters that lead to complementary flavor bounds. Limits on $\mu \to e\gamma$ and $b \to s\gamma$ are particularly constraining for generic models of compositeness. We explicitly calculated these processes for the RS model, quantifying the amount of tuning required to satisfy existing bounds and highlighting the flavor observables that are most sensitive to new RS states [1, 3]. We found that both the minimal and custodially protected RS model require additional structure to avoid dipole flavor bounds within the anarchic Yukawa scenario.

Phenomenology of emergent electroweak symmetry & natural SUSY

Another way to generate a natural spectrum from compositeness is to invoke Seiberg duality to identify part of the electroweak gauge group with the magnetic dual of a confining supersymmetric gauge theory. In the minimal realization of this model, the Higgs and top are magnetic quarks while the remaining Standard Model matter particles are weakly gauged elementary superfields in the electric sector. This framework is of particular interest as a UV realization of the 'stealth stop' scenario where the lightest stop is nearly degenerate with the top quark. In ongoing work, we are using this model as a benchmark to examine experimental searches for stealth stops beyond simplified models [4].

Motivated by natural SUSY with R-parity violation (RPV), one may also consider effective theories where stops decay into a pair of bottom quarks. The same-sign di-lepton (SS2L) channel is a rich place to look for new Majorana fermions such as the gluino. This offers a way to control the QCD background of the RPV decays of boosted light stops coming from gluino pair production. We are currently studying the discovery reach of an SS2L search combined with jet substructure to determine the stop mass [5].

In past work I have calculated the loop-level contributions to $B_s \to \mu^+\mu^-$ in the general Minimal Supersymmetric Standard Model (MSSM), focusing on novel regions at moderate $\tan\beta$ where interference can reduce the rate below the Standard Model prediction [6]. These were incorporated into the the `SUSY_FLAVOR` code which calculates flavor-changing observables in the general MSSM [7].

Goldstone fermion dark matter

Nonlinear realizations describe the low-energy degrees of freedom of strongly coupled theories with spontaneously broken symmetry. When combined with SUSY, the Goldstone bosons of these theories are complex fields with 'Goldstone fermion' superpartners. These, in turn, offer novel 'weakly interacting massive particle' (WIMP) dark matter candidates.

Typical WIMP candidates in the MSSM require a tuned spectrum to simultaneously obtain the observed dark matter relic abundance and avoid the upper limit on the WIMP–nucleon cross section from direct detection experiments. We showed that Goldstone fermions can avoid this tuning since their annihilation rate is naturally fixed by interactions within the nonlinearly realized sector while the direct detection cross section is controlled by mixing with the Higgs sector [8]. We found that for a global U(1) broken at the TeV scale, one naturally obtains a 100 GeV scale Higgs-portal WIMP candidate whose direct detection rate is suppressed by three orders of magnitude. This effective theory can also furnish indirect detection signals through anomaly-induced couplings of the Goldstone boson to photons and gluons. We are currently exploring the extent to which these signals can be Sommerfeld enhanced by matching to a non-relativistic theory with a regulated, singular potential [9].

Future directions

I would like to continue to combines ideas from the above research threads into innovative models of natural SUSY. For example, the flavor structure of minimal supersymmetric composite electroweak model above is largely put in by hand. On the other hand, RS offers an intuitive picture for generating realistic flavor hierarchies in terms of partial compositeness. This picture is not trivially compatible with the Higgs structure of the previous model and it would be interesting to investigate whether the two ideas can be combined.

Similarly, recent claims of a 130 GeV line in the FERMI γ-ray spectrum may be interpreted in terms of a dark matter. Non-minimal pseudo-Goldstone Higgs models often have singlets that can be used as dark matter candidates with masses close to that of the Higgs, but have trouble generating the 130 line since Higgs-singlet couplings contribute to a photon continuum that is not observed. Supersymmetrizing the model and identifying the Goldstone fermion (rather than boson) as dark matter may allow additional handles to sequester the Higgs portal from the Goldstone fermion.

Finally, the next three years are especially exciting to work at the phenomenological frontier. In addition to the LHC preparing for its 14 TeV run, dark matter bounds will approach the cosmic neutrino bound and several rare flavor decays (including $B_s \to \mu\mu$ and $\mu \to e\gamma$) will be probed to their Standard Model expectations. I look forward to interpreting these bounds in terms of composite models and, in turn, working to find novel ways to discriminate between models of new physics.

References

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