Lattice Beyond the Standard Model Summary

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Why study BSM theories on the lattice?

It is known that there is physics beyond the Standard Model from cosmology.

The biggest mysteries include the nature of dark matter, dark energy, and inflation (or something like it) in the early universe.

An understanding of the hierarchy of scales of particle masses is unexplained. Symmetries might explain how such scales can emerge "naturally," but no obvious (observed) symmetry protects scalar masses, so why is the Higgs light?

Neutrinos do not have masses in the Standard Model, so interesting to explore physics that can generate them.

Strongly coupled physics might play a role in explaining some or all of these mysteries, so worth pursuing first principles, numerical investigations of theories that might have desirable features and give some insight into these problems.

USQCD lattice BSM

Class A USQCD proposals in BSM this year mostly focused on trying to understand Higgs naturalness by looking at models that have an emergent light scalar that could be identified with the Higgs. Current proposals:

Kuti et al.: Studying near conformal gauge theory with a massless fermion flavor doublet in the two-index symmetric (sextet) representation of the SU(3) color gauge group. (Also calculating α_s in 2+1 flavor QCD)

Neil et al.: 4+4 theory, SU(4) gauge theory with fermions charged under the fundamental and two-index antisymmetric representations.

Kuti proposal

Using sextet model as example of near-conformal gauge theory with possible emergent light scalar. Fitting numerical data to dilaton effective field theory (EFT) to study light degrees of freedom.

Difficult to study the theory when Goldstone boson Compton wavelength is small relative to lattice size. Can study this in epsilon-regime, where Compton wavelength is much larger than lattice size. Fitting to these tow regimes is complimentary, and helps determine low energy constants of the EFT and test how well a given EFT formulation describes the numerical data.

Renormalization group techniques that have been used to study β function and mass anomalous dimensions in near-conformal theories being applied to calculate α_s in 2+1 flavor QCD. (Two different proposals, Kuti and Hasenfratz). Synergy of the BSM studies and Standard Model parameter determinations.

Neil proposal

First group to carry out extensive numerical simulations with dynamical fermions in two distinct representations.

Previous work was 2+2, with two flavors in each representation. 2+2 theory not a realistic composite Higgs model, since 2+2 theory is "QCD-like," far from the conformal window.

In the 4+4 theory, with four flavors in each representation, analytic estimates indicate the theory is near-conformal. The plan is to calculate the beta function and the anomalous dimensions of fermion operators using gradient flow renormalization group methods.

Using Wilson fermions in order to maintain exact flavor symmetry. To reach strong gradient-flow couplings, have added heavy (cut-off size mass) Pauli-Villars fermions to theory.

Other projects by USQCD members (no proposals this year)

LSD Collaboration studying SU(3) $N_f = 8$ theory as an example of a (near-) conformal theory with a light scalar. Testing fits of lattice data to dilaton EFT to explore the light sector.

N=4 SUSY Yang-Mills by Catterall, Giedt and collaborators. Can reach strong coupling for SU(2), and numerical results match expectations from holography for dependence of Wilson loops on the coupling.

Lattice formulations extended to cylindrical manifolds to implement radial quantization (Brower, Flemming and collaborators). May be used to calculate near-conformal theories without unrealistically large lattices.

Lattice gravity by JL, Unmuth-Yockey, and collaborators. Evidence for emergence of semi-classical gravity, including a Newtonian limit, and for the existence of a non-trivial continuum limit. Supports Weinberg's asymptotic safety conjecture for gravity.

Conclusion

Lattice can be used to study strongly coupled quantum field theories. What we learn could inspire solutions to outstanding problems in high energy physics.

Also provides motivation and testing ground for developing new tools that might be applied to precision QCD.