Composite Higgs, Dark Matter and New Strong Dynamics with Lattice Field Theory

Executive Summary/Introduction

Composite Higgs Physics

Composite Dark Matter

Supersymmetry Window into Quantum Gravity

Algorithmic Research for New Methods

Software and Computational Requirements

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Executive Summary

- **Composite Higgs** boson and **composite dark matter** particle(s) are important candidates for BSM physics, that may appear as bound states within strongly-coupled theories. Critical is establish generic dynamical machanisms and low **energy effete theories (EFT)**

- Near **conformal fixed point** Gauge Theories may provide a new dynamical explanation for the properties of these particles. Generic features of near CFTs can suggest **novel signatures** for composite strong dynamics at the high luminosity upgrade of the LHCs and for astrophysical or underground searches for dark matter.

- **Supersymmetry** may also play a special role by **stabilizing** the dynamics associated with approximate scale invariance. The **AdS/CFT** (or gravity/gauge) correspondence enbables lattice gauge theories to **explore quantum gravity**.

Recent Workshops

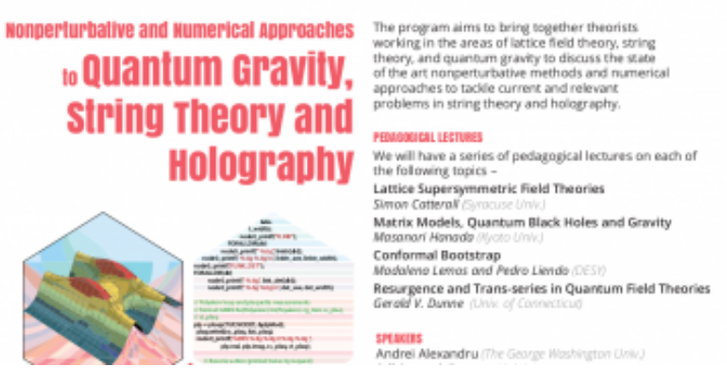
April 5-8, 2018 Univ of Colorado Boulder

Lattice for Beyond the Standard Model Physics 2018
http://www-hep.colorado.edu/~eneil/lbsm18/

Jan 27-Feb 3, 2018 ICTS Bangalore India

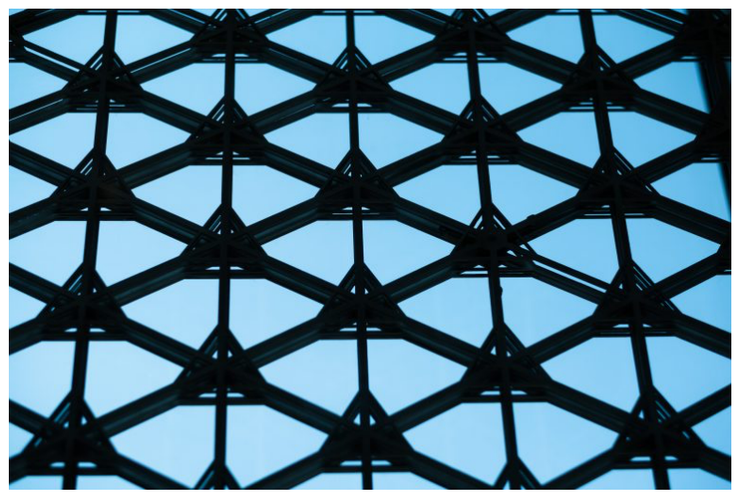
NONPERTURBATIVE AND NUMERICAL APPROACHES TO QUANTUM GRAVITY, STRING THEORY AND HOLOGRAPHY
https://www.icts.res.in/program/NUMSTRINGS2018

ICTS INTERNATIONAL CENTRE for THEORETICAL SCIENCES
TATA INSTITUTE OF FUNDAMENTAL RESEARCH



Jan 8-13, 2018: Simon Center Stony Brook

Continuum and Lattice Approaches to the Infrared Behavior of Conformal and Quasi- Conformal Gauge Theories: Jan. 8-12, 2018
http://scgp.stonybrook.edu/archives/21358



Algorithmic Research for New Methods

- The range of dynamics in strongly interacting field theories represent a **(vast) unexplored theoretical** landscape which is undergoing the development of new methods

- Direct assault on (near) Conformal Field Theory**: Conformal bootstrap** give exact constraints**,** Minkowski space mass deformed **Truncated Hamiltonian** in conformal basis, lattice field on **curved manifold** using Quantum Finite Element give exponential scale separation in radial quantization et al.

- Interesting intersection of ideas from **tensor networks, Multigrid, entanglement** and **even quantum computing** have with potentially to advance BSM theories and I benefit lattice QCD and condensed matter

Backup details topics

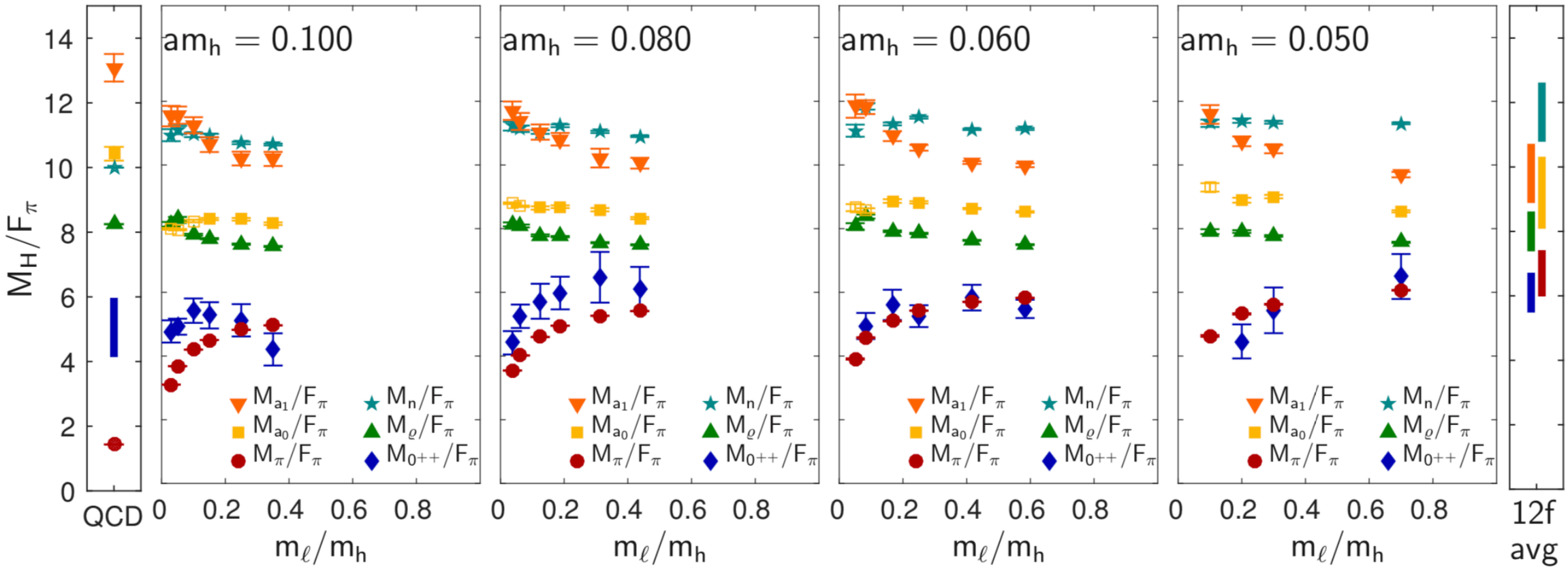
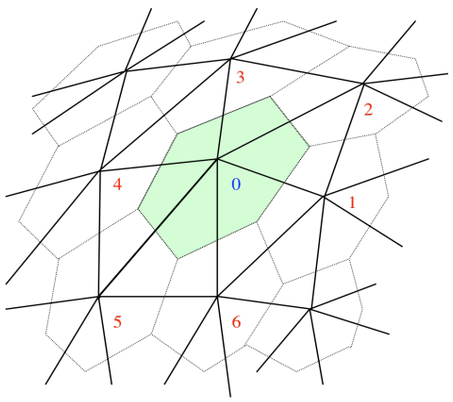
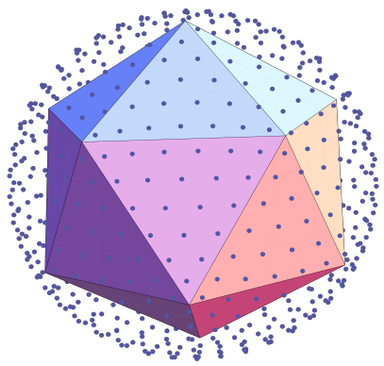
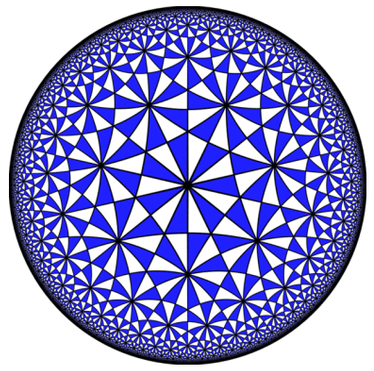


Figure 2. Ratios of the masses of π, ρ, a_0, a_1, n, and of the 0^{++} over F_π. The left panel shows results for QCD taken from the PDG [14], the right panel averages for a (mass deformed) 12 flavor theory [11, 15–17].







Composite Higgs Dynamics

Basic idea: Electroweak symmetry breaking is triggered by a new, strongly interacting sector.

- Three massless pions are absorbed by the SM vector bosons but the rest of the strongly interacting sector is experimentally discoverable.

- Two scenarios:
  - pNGB : the Higgs is a Goldstone boson, its mass generated through interactions
  - Higgs emerges light as a softly broken dilaton-like state

- Extensions:
  - Large scale separation (mass split systems or 4-fermion interaction)
  - mass generation of SM fermions (4-fermion coupling or partial compositeness)

- **There are several viable composite Higgs models - most are near conformal**
- **No experimental results of new sector yet**
- **Goal is to understand the general features of these systems and predict models based on emerging experimental data**

Composite Higgs Dynamics

Lattice simulations explore the general properties of near-conformal systems:

<u>Straightforward calculations:</u>

- **Connected spectrum of new sector (meson or baryon)**
- **Finite-temperature phase structure (gravity waves?)**

<u>Challenging calculations:</u>

- **Properties of the light Higgs**
- **Parameters of low energy EFT /embedding the SM**
- **anomalous dimensions —> SM fermion mass generation**

<u>Extremely challenging calculations:</u>

- **Chiral limit of near-conformal models / connecting to ChPT**
- **Extensions with 4-fermion interactions / UV completeness**

Composite Dark Matter

Basic idea: dark matter as a composite bound state of some hidden sector. Can have very different interactions with Standard Model at different energies/temperatures (form factors.)

Strong self-interactions may allow for different astrophysical signatures. Possibility of charged composite states related closely to DM allow for novel collider searches.

Straightforward calculations:

- **Spectrum of dark hadrons (meson or baryon)**
- **Form factors (vector —> photon, scalar —> Higgs)**
- **Finite-temperature phase structure (gravity waves?)**

Challenging calculations:

- **Dark nuclear interactions - binding of large dark nuclei?**
- **Dark hadron scattering**
- **Spectrum, matrix elements of dark glueballs**

Extremely challenging calculations:

- **Dark matter annihilation processes**
- **Dark glueball scattering**

Supersymmetry to Quantum Gravity

- Low Energy SUSY is still (barely) alive BUT it also offers a frame work for low mass scalar stabilization for low mass “composite Higgs/Dark Matter” Dynamical SUSY symmetry breaking is an important open issue.

- The AdS/CFT duality maps strong/weak gauge theories to strong/ weak dual (string). Fertile framwork for modeling IR behavior of field theory use in Hot QCD, condensed matter and now in BSM near conformal theories.

- Gravity: Of particular interest are theories which possess a holographic dual - quantum field theories in flat spacetime which are thought to be equivalent to a gravitational system. The strongly coupled quantum field theories then provide a probe of both black holes and quantum gravity in the dual theory.