Orthogonal Technicolor with Isotriplet Dark Matter on the Lattice

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CP^3 - Origins
Particle Physics & Cosmology

Introduction

- The technicolor theories provide natural dark matter (DM) candidates.
- The DM candidate is the lightest technibaryon or other composite state protected by symmetry. S. Nussinov, Phys. Lett. B **165**, 55 (1985). and R. Foadi, M. T. Frandsen and F. Sannino, arXiv:0812.3406 [hep-ph].
- This scenario naturally leads to asymmetric DM, but also symmetric DM is possible. A. Belyaev, M. T. Frandsen, S. Sarkar and F. Sannino, arXiv:1007.4839 [hep-ph].
- The DM particle can also be light if it is a pseudo Goldstone boson, e.g. iTIMP. M. T. Frandsen and F. Sannino, arXiv:0911.1570 [hep-ph]

Orthogonal technicolor

- SO(4)-gauge theory with two vector representation fermions
- The theory has a possibly light dark matter candidate called ITIMP[1] (M. T. Frandsen and F. Sannino, arXiv:0911.1570)
- For two Dirac fermions in a real representation the chiral symmetry breaking pattern is: $SU(4) \rightarrow SO(4)$. This gives nine Goldstone bosons, of which three are eaten by SM gauge bosons.

[1] Isotriplet Technicolor Interactive Massive Particle

- The enlarged chiral symmetry follows from the property of Dirac operator

$$(\not{D} + m)C\gamma^5 = C\gamma^5(\not{D} + m)^*,$$

where $C = i\gamma^0\gamma^2$ is the charge conjugation operator.

- Six additional Goldstone bosons with technibaryon charge form triplets.

- The ITIMP is the neutral isospin zero component of weak complex triplet

$$T^+,\ T^0,\ T^-$$

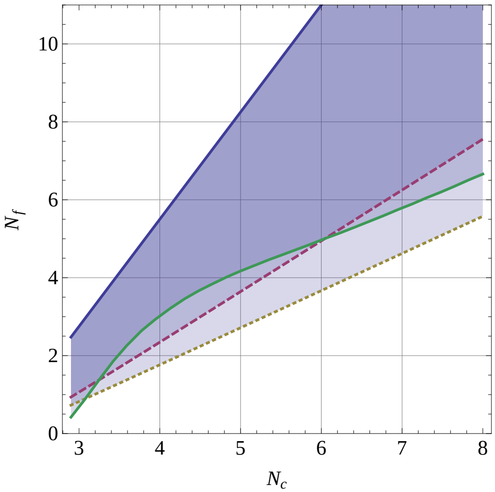
possessing a technibaryon number.

- Compared to MWT, the real gauge group removes the fractionally charged states composed of a techni quark and techni gluon, which would be present in SU(N) theory with adjoint fermions.

- No Witten anomaly.

- SO(4) is semi simple SO(4)= SU(2)$\otimes$SO(3) and it has a non-trivial center Z_2.

- The two-loop β-function of the theory does not have an infrared fixed point. Maybe a good theory for walking.



Conformal window in two, three and four-loops for SO(N) theories with fundamental fermions.

Lattice study

Based on AH, C. Pica, F. Sannino and U. I. Sondergaard, arXiv:1211.5021 [hep-lat].

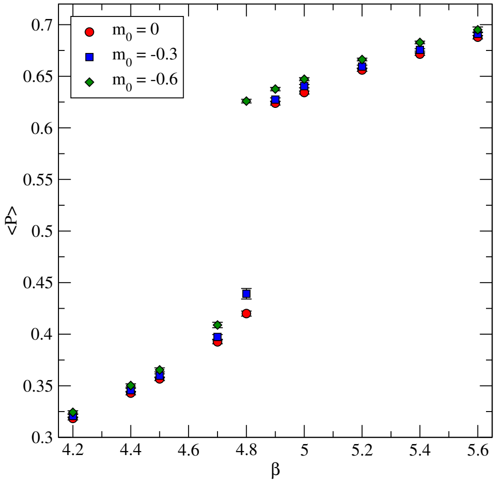
Goals of the project:

1. Map out the phase diagram in (β, m_0)-plane
2. Confirm that the chiral symmetry is broken.
3. Find out the chiral symmetry breaking pattern.
4. Calculate the running of the coupling. Is theory running, walking or conformal?
5. Calculate properties of dark matter: Form factors, etc.

Lattice phase diagram

- We map out the phase diagram in (β, m_0)-plane.
- Our main aim is to find the zero fermion line as well as the strong coupling bulk phase transition line.
- The bulk phase transition is located by a discontinuity in Plaquette expectation value.
- The initial scan is done with a small volume $L = 16 \times 8^3$
- Bulk phase transition in SO(N)-gauge theories in a $\beta \Rightarrow$ large lattices required.

Bulk phase transition



PCAC quark mass

- We use Partial Conversation of Axial Current to determine the quark mass
- On lattice:

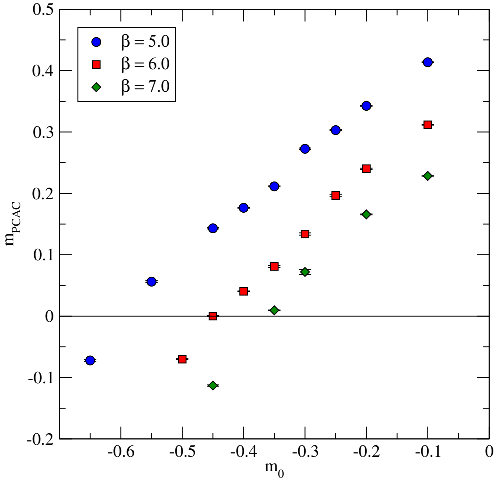
$$m_{\mathrm{PCAC}} = \lim_{t\to\infty} \frac{1}{2}\frac{\partial_t V_{\mathrm{PS}}}{V_{\mathrm{PP}}},$$

where the currents are

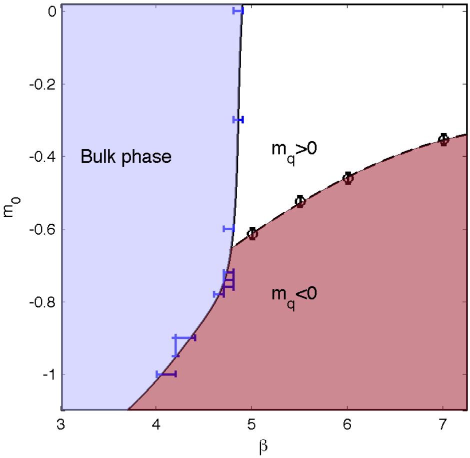
$$V_{\mathrm{PS}}(x_0) = a^3 \sum_{x_1,x_2,x_3} \langle \bar{u}(x)\gamma_5 d(x)\bar{u}(0)\gamma_5 d(0)\rangle$$

$$V_{\mathrm{PP}}(x_0) = a^3 \sum_{x_1,x_2,x_3} \langle \bar{u}(x)\gamma_0 d\gamma_5(x)\bar{u}(0)\gamma_0\gamma_5 d(0)\rangle.$$

Examples of zero mass extrapolation



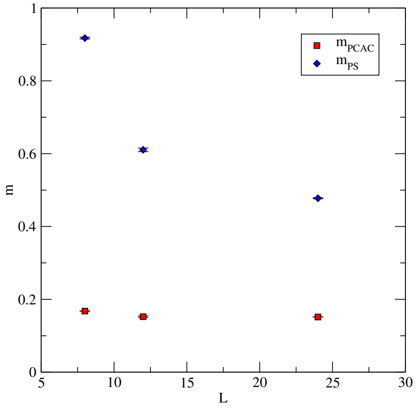
Lattice phase diagram



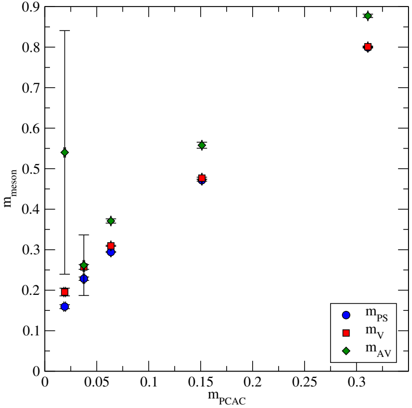
Meson spectroscopy

- For studies of meson spectroscopy we picked the bare coupling $\beta = 7.0$
- Simulation were performed with lattices of $V = 64x12^3$ and $V = 64x24^3$
- The lattice $V = 64x12^3$ still too small for spectroscopy.

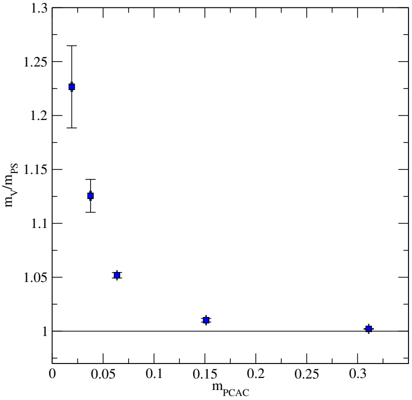
Finite volume effects



Meson masses



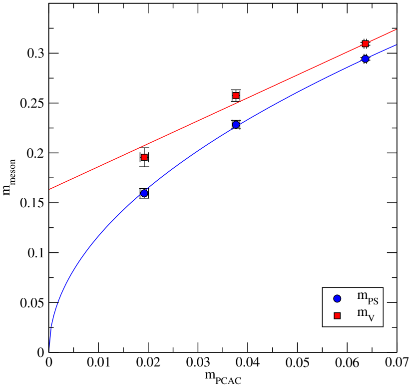
Ratio of vector and pseudoscalar meson



Different fits for chiral limit

meson fit	fit function	best parameter	χ^2/dof
ps chiral	$a\sqrt{m}$	$a = 1.167(6)$	0.43/2
ps conformal	am	$a = 4.69(3)$	364/2
ps alt. 1	$a + bm$	$a = 0.111(6)$ $b = 2.9(1)$	6.4/1
ps alt. 2	$a + b\sqrt{m}$	$a = -0.001(10)$ $b = 1.17(4)$	0.41/1
vector chiral	$a + bm$	$a = 0.16(1)$ $b = 2.3(2)$	3.3/1
vector conformal	am	$a = 4.91(3)$	273/2
vector alt. 1	$a\sqrt{m}$	$a = 1.231(6)$	18/2
vector alt. 2	$a + b\sqrt{m}$	$a = 0.07(2)$ $b = 0.96(7)$	0.69/1

Chiral fits


0.3
0.25
0.2
0.15
0.1
0.05
0
m_meson
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
m_PCAC
m_PS
m_V

Conclusions

- Orthogonal Technicolor is a viable technicolor theory candidate.
- We mapped out the phase diagram in (β, m_0)-plane.
- We found behavior consistent with chiral symmetry breaking.
- Finite volume effects might still be a problem.
- To do: Measure scalar mass, exited states, and form factors.