Simulations of SO(4) gauge theory with two fundamental Wilson fermions

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CP^3 - Origins
Particle Physics & Cosmology

Introduction - Why to study SO(4) theory

- The work is motivated by a possible dark matter candidate called ITIMP[1] (M. T. Frandsen and F. Sannino, arXiv:0911.1570)
- The ITIMP is the neutral isospin zero component of weak complex triplet
$$T^{+},\ T^{0},\ T^{-}$$
possessing a technibaryon number.
- To agree with the cosmological observations, the dark matter particles need a mass less than 100GeV which is relatively light compared to the expected masses of Techni color particles (about 1TeV).
- This can be achieved if the particles are (pseudo) Goldstone bosons.

[1] Isotriplet Technicolor Interactive Massive Particle

- For two Dirac fermions in a real representation the chiral symmetry breaking pattern is: $SU(4) \rightarrow SO(4)$. This gives 9 Goldstone bosons, of which three are eaten by SM gauge bosons.
- Six additional Goldstone bosons with technibaryon charge form triplets. The isospin zero component is the ITIMP
- For SU(N) gauge theories with fermions in adjoint representation, this could mean fractionally charged bound states composing of a techni quark and techni gluon.
- To avoid this problem we consider SO(N) gauge theories with fundamental fermions.

SO(4) with two fundamental fermions

- For a specific model we choose SO(4) with two fundamental fermions.
- SO(3) would probably be conformal (compare to MWT).
- SO(4) is semi simple SO(4)= SU(2)$\times$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.

Lattice study

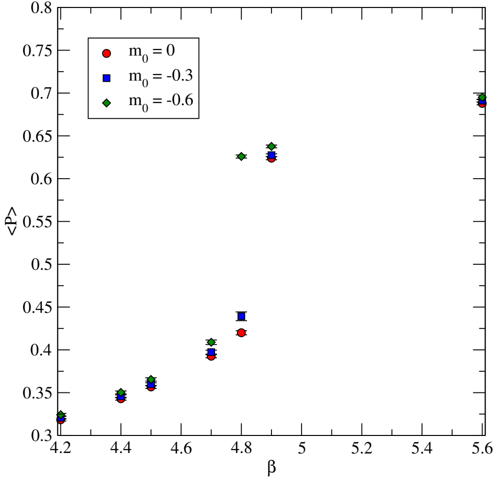
Goals of the project:

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?

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



PCAC quark mass

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

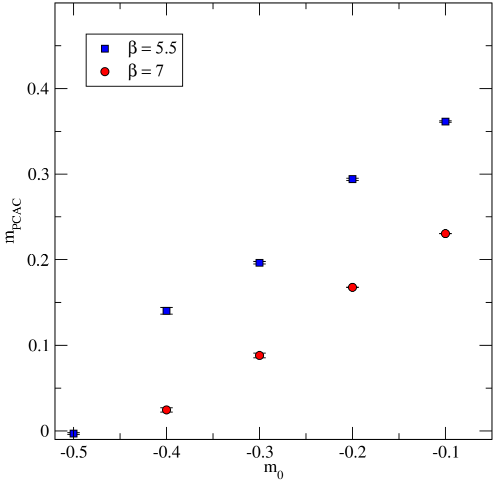
$$m_{\mathrm{PCAC}} = \lim_{t\to\infty} \frac{1}{2} \frac{\partial_t V_{\mathrm{PS}}}{V_{\mathrm{PP}}},$$

where the currents are

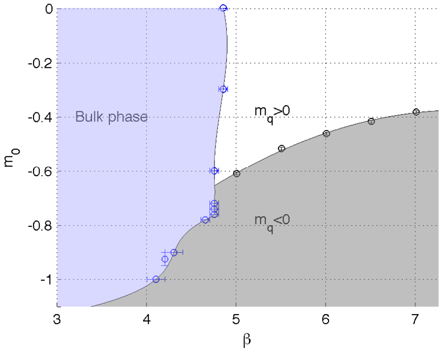
$$V_{\mathrm{PS}}(x_0) = a^3 \sum_{x_1,x_2,x_3} \langle \bar{u}(x)\gamma_5 d(x) \bar{u}(0)\gamma_5 d(0)\rangle$$

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

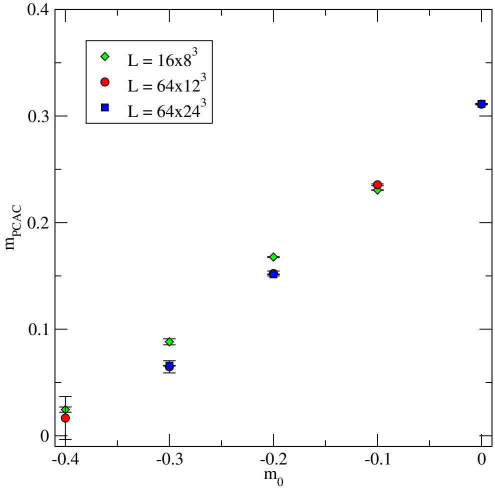
Examples of zero mass extrapolation



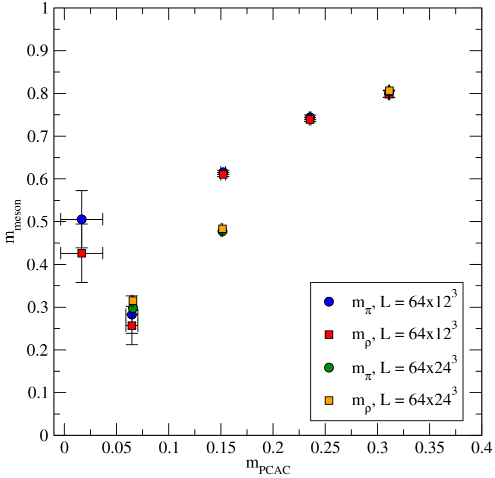
Phase diagram



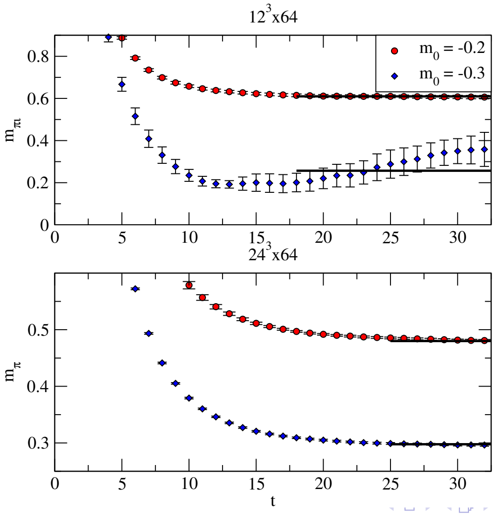
- For large lattice studies we picked up two values of $\beta = 5.5$ and 7.0
- Simulation were (are) performed with lattices of $V = 64x12^3$ and $V = 64x24^3$
- Results are preliminary
- I will only show results for $\beta = 7$.


L = 16x8^3
L = 64x12^3
L = 64x24^3
m_PCAC
m_0
0.4
0.3
0.2
0.1
0
-0.4
-0.3
-0.2
-0.1
0

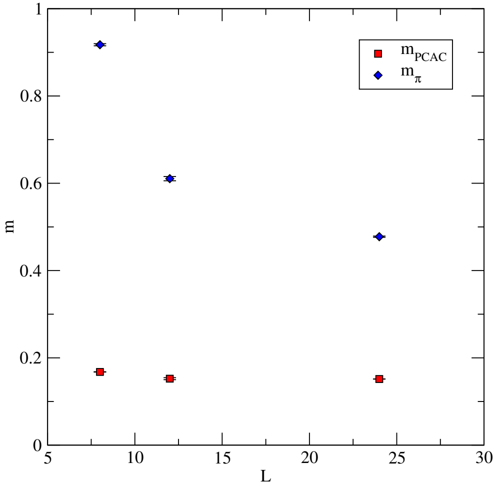
Meson masses for $\beta = 7$



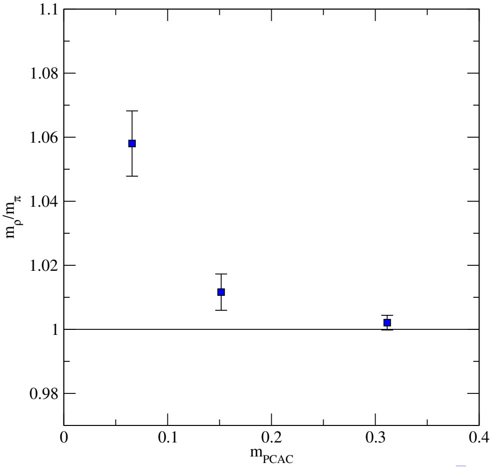
Effective mass $\beta = 7$



Finite size effects $\beta = 7$ and $m_0 = -0.2$



Ratio of vector and pseudoscalar meson $\beta = 7$ $V = 64 \times 24^3$



Conclusions

- We mapped out the phase diagram in (β, m_0)-plane.
- The finite volume effects are large and not well in control.
- There are hints of chiral symmetry breaking. Simulations with large volume and smaller mass are needed to confirm this.
- Future goals
  - Check that the chiral symmetry pattern is $\mathrm{SU}(4) \to \mathrm{SO}(4)$.
  - Find out if the theory is running or walking.