

Improved Lattice Spectroscopy of Minimal Walking Technicolor

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Outline

1 Introduction

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Motivation

Improved
Lattice
Spectroscopy
of Minimal
Walking
Technicolor

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Introduction

Conformality

Systematic
Spectroscopy

Results

Conclusions

- Electroweak symmetry breaking in nature about to be probed
- Dynamical EWSB remains a possible mechanism
- Requires new gauge sector with low N_c and N_f which is near-conformal
- Non-perturbative question

Outline

① Introduction

② Conformality

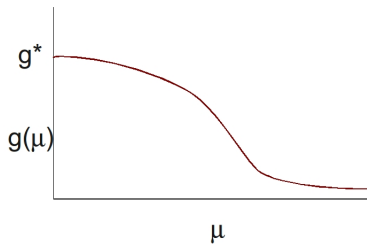
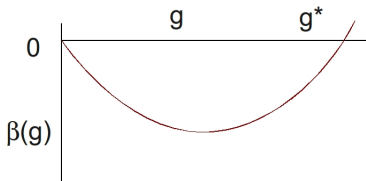
③ Systematic Spectroscopy

④ Results

⑤ Conclusions

IR Conformal

- We are interested in IR conformal theories



Hyper-scaling

- Conformal theory must have all $m, M = 0$
- Consider small masses as perturbation
- Have $\gamma_m = -\gamma_{\langle\bar{\psi}\psi\rangle}$
- RG analysis provides

$$M \sim m^\rho$$

- $\rho = \frac{1}{1+\gamma_*}$ and $\gamma_* = \gamma(g_*)$, $0 \leq \gamma_* \leq 2$
- $\gamma_* \sim 1$ might support idea of near-conformal DEWSB
- Note all M scale together. Very different from QCD, χ_{SB}

Finite Size Scaling

- Simulations performed in finite volume, spatial length L_s
- ML_s becomes universal function

$$ML_s = f(x)$$

- $x = N_s(am)^\rho$
- Allows direct comparison of data across lattices, gives improved information

Conformal Comparison

QCD

- $m_{\text{PS}} \sim m^{\frac{1}{2}}$
- $\frac{m_{\text{PS}}}{m_{\text{V}}} \xrightarrow{m \rightarrow 0} 0$
- Volume effects $\sim e^{-m_{\text{PS}} L_s}$

IR Conformal

- $m_{\text{PS}} \sim M \sim m^{\rho}$
- $\frac{m_{\text{PS}}}{m_{\text{V}}} \sim 1$
- Volume effects $(L_s m_{\text{PS}})^{\alpha}$

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Minimal Walking Technicolor

- $SU(2)$ theory with two (Dirac) flavours of adjoint fermion
- Candidate model for new gauge sector of near-conformal technicolor theory
- Minimal N_c, N_f to minimise FCNC, electroweak precision contributions
- Attracted significant phenomenological and lattice attention
- Previous simulations have provided some evidence for near-conformal behaviour
 - Renormalisation flow analysis
 - Spectroscopic evidence
- Systematics largely unexplored

Simulation

- Simulation details found in [DDL⁺10b, DDL⁺10a]
- Wilson fermions $\Rightarrow am \neq 0$
- Configs from *HiRep* code for arbitrary N_c , N_f and fermion representation.
- Fixed lattice spacing $\beta = 2.25$, range of bare masses and volumes

Local Results

- Significant evidence for non QCD-like behaviour
 - Scaling of pseudoscalar mass
 - Ratio of meson masses
 - Scaling of decay constants
- Scaling of masses, decay constants, indicates γ_* small,
 $0.05 < \gamma_* < 0.2$

Spectroscopy

- Original analysis involved local correlators

$$C_{\Gamma}^l(t) = a^6 \sum_{\vec{x}} \langle \bar{\psi}(\vec{x}, t) \Gamma \psi(\vec{x}, t) \bar{\psi}(\vec{0}, 0) \Gamma \psi(\vec{0}, 0) \rangle$$

- Non-singlet: consider only “connected” contraction
- Employ modified *chroma* software, general N_c , N_f , R
- Allows use of ready made smearing routines
- Wall smearing expected to have lower overlap with excited states

$$C_{\Gamma}^s(t) = a^6 \sum_{\vec{x}} \langle \bar{\psi}(\vec{x}, t) \Gamma \psi(\vec{x}, t) \sum_{\vec{y}, \vec{z}} \bar{\psi}(\vec{y}, 0) \Gamma \psi(\vec{z}, 0) \rangle$$

Observables

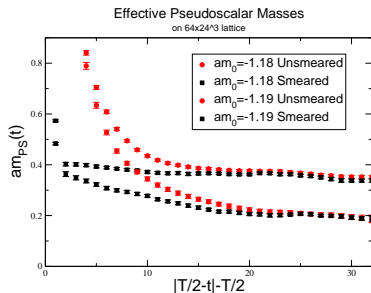
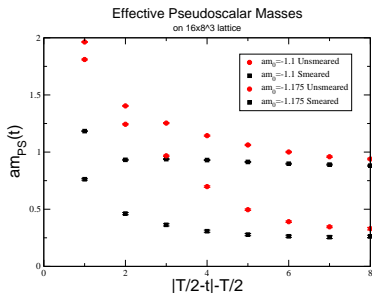
- Masses extracted from asymptotic large-time behaviour of $C(t)$

$$C_{\gamma_5} \xrightarrow{t \rightarrow \infty} \frac{a^3}{V_s} \frac{G_{\text{PS}}^2}{2m_{\text{PS}}} \left(e^{-m_{\text{PS}}t} + e^{-m_{\text{PS}}(T-t)} \right)$$

- Pseudoscalar decay constant obtained from PCAC relation

$$F_{\text{PS}} = \frac{2mG_{\text{PS}}}{m_{\text{PS}}^2}$$

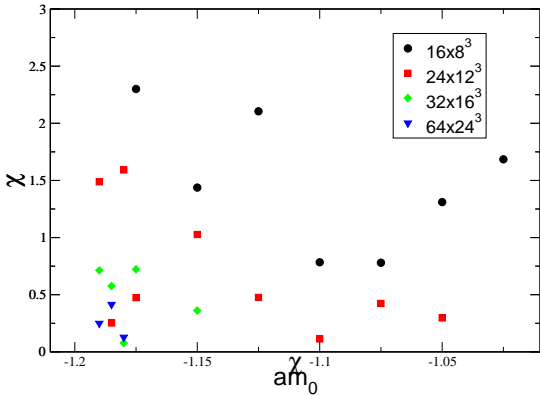
Improved Plateaux



Replicated across observables

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Pull between smeared and unsmeared results
PCAC mass



$$\chi = \sqrt{\frac{(m_s - m_l)^2}{\sigma_s^2 + \sigma_l^2}}$$

Effective Observables

- Experimented with different effective observables

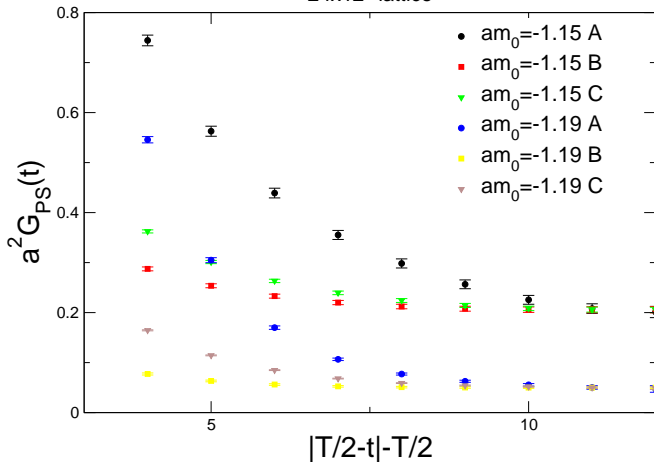
$$a^2 G_{\text{PS}}(t) = \sqrt{V_s \frac{2am_{\text{PS}} C_{\gamma_5}(t)}{e^{-m_{\text{PS}}t} + e^{-m_{\text{PS}}(T-t)}}$$

- Ambiguity in definition
- Could use $m_{\text{PS}}(t)$ or m_{PS} for example
- Leads to little effect
- Also for smeared correlators

Effective amplitudes

Effective Pseudoscalar Amplitudes

24×12^3 lattice



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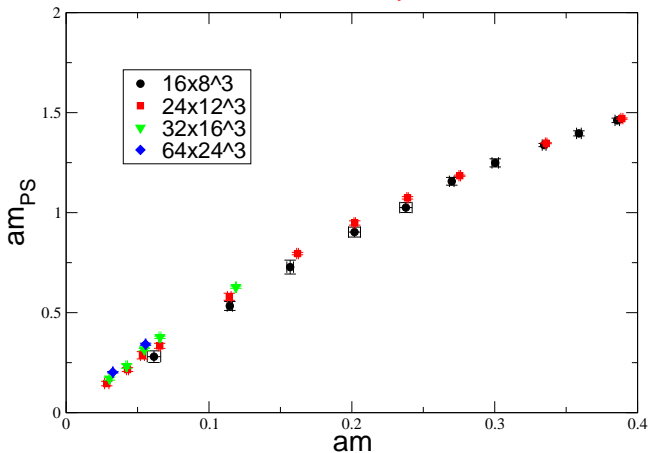
Meson Masses

- Can extract am_{PS} , am_V without difficulty
- am_S and am_{AV} present problems, insufficient statistics.
- Results show lower uncertainties due to smaller contribution from excited states
- Discrepancies are apparent at small volume
- Systematically combine two data sets
 - Gives larger uncertainties where systematics present
 - Reduces uncertainties where systematics under control, due to increased accuracy from smearing

Pseudoscalar Meson

Pseudoscalar Meson Mass

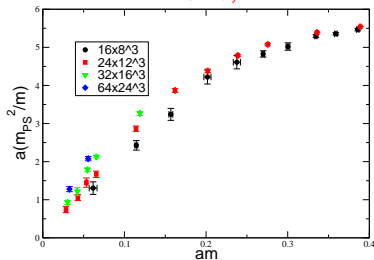
Preliminary



Pseudoscalar Mass Scaling

Ratio of pseudoscalar mass squared to quark mass

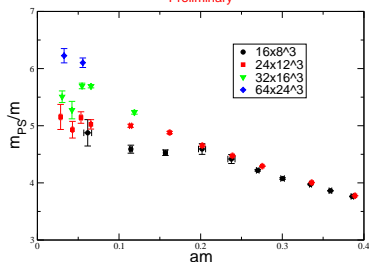
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$$\frac{m_{\text{PS}}^2}{m} \sim \xrightarrow{m \rightarrow 0} 0$$

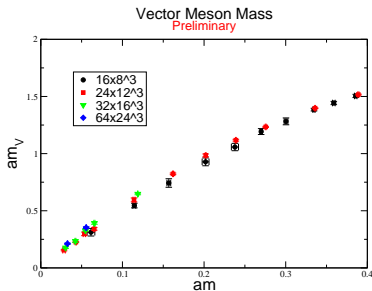
Ratio of pseudoscalar mass to quark mass

Preliminary

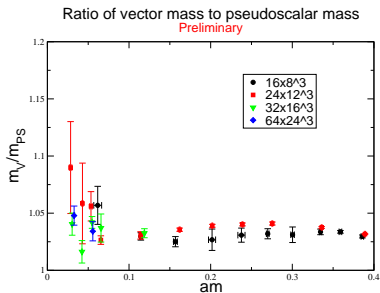


$$\gamma_* > 0?$$

Vector Meson



$m_V > m_{PS}$ as expected for
non-singlet

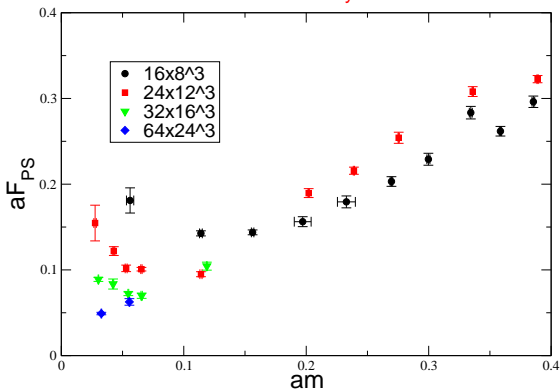


$$\frac{m_V}{m_{PS}} \xrightarrow{m \rightarrow 0} \gg 1$$

Pseudoscalar Decay Constant

Pseudoscalar Decay Constant

Preliminary



Large volume effects present

Finite Size Scaling m_{PS}

PRELIMINARY

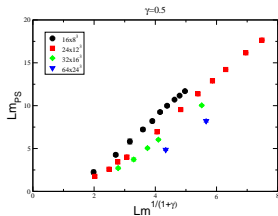
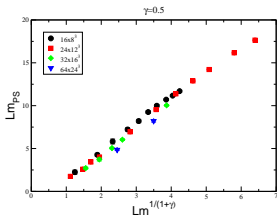
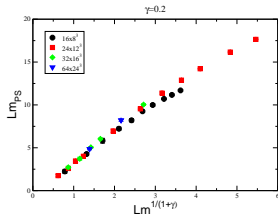
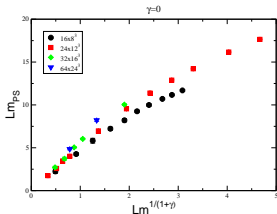
Introduction

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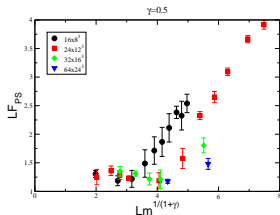
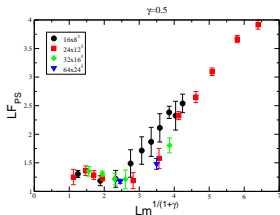
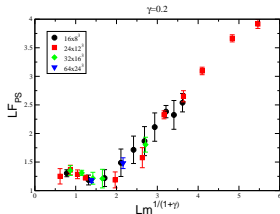
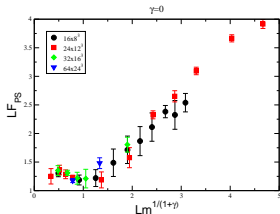
Results

Conclusions



Finite Size Scaling F_{PS}

PRELIMINARY



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Summary

- Supported the results in [DDL⁺10a, DDL⁺10b]
- Clarified where systematics are under control, and where not
- Allowed for systematic uncertainties where necessary
- Provided more precise results where possible
- Results in more robust results, allowing for more confident conclusions
- Emphasises need to be at large volume, small mass

Plateaux

- Define effective observable $M(t) \xrightarrow{t \rightarrow \frac{T}{2}} M$
- Examine behaviour at large times
- Fit over range of t over which $M(t)$ roughly constant

Combining Data Sets

$$M_1 \pm \sigma_1$$

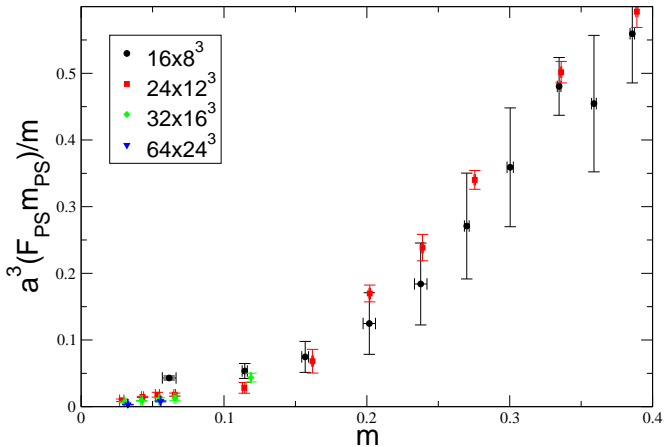
$$M_2 \pm \sigma_2$$

$$\begin{aligned} M' &= \frac{\frac{M_1}{\sigma_1^2} + \frac{M_2}{\sigma_2^2}}{\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2}} \\ &= \frac{\sigma_2^2 M_1 + \sigma_1^2 M_2}{\sigma_1^2 + \sigma_2^2} \end{aligned}$$

$$\begin{aligned} \sigma' &= \frac{1}{\sqrt{\frac{1}{\sigma_1^2} + \frac{1}{\sigma_2^2}}} \times \left(1 + \frac{(M_1 - M_2)^2}{\sigma_1^2 + \sigma_2^2} \right) \\ &= \frac{\sigma_1 \sigma_2}{\sqrt{\sigma_1^2 + \sigma_2^2}} \times \left(1 + \frac{(M_1 - M_2)^2}{\sigma_1^2 + \sigma_2^2} \right) \end{aligned}$$

GMOR Relation

GMOR Relation





Luigi Del Debbio, Biagio Lucini, Agostino Patella, Claudio Pica, and Antonio Rago.

Mesonic spectroscopy of Minimal Walking Technicolor.
2010.



Luigi Del Debbio, Biagio Lucini, Agostino Patella, Claudio Pica, and Antonio Rago.

The infrared dynamics of Minimal Walking Technicolor.
2010.