Confining vs. conformal scenario for SU(2) with 2 adjoint fermions Mesonic spectrum

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In collaboration with L. Del Debbio, B. Lucini, A. Patella, A. Rago
based on Phys. Rev. D **80** (2009) 074507,
arXiv:0907.3896, arXiv:1004:3206, arXiv:1004.3197

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Motivation

The Standard Model

Bosonic sector

$$\begin{array}{ccccc} SU(3)_c & \times & SU(2)_L & \times & U(1)_Y \\ G_{\mu\nu} & & W_{\mu\nu} & & B_{\mu\nu} \end{array}$$

Fermionic sector

$$\begin{pmatrix} u^i_L \\ d^i_L \end{pmatrix} \quad , \quad u^i_R \quad , \quad d^i_R$$

$$\begin{pmatrix} e^i_L \\ \nu^i_L \end{pmatrix} \quad , \quad e^i_R \quad , \quad \nu^i_R(?) \qquad i = 1, 2, 3$$

Higgs sector

Higgs field
– complex scalar field in the $\frac{1}{2}$ repr. of $SU(2)_L$
Mexican-hat potential
– $SU(2)_L \times U(1)_Y \to U(1)_{EM}$ and Higgs mechanism
Yukawa coupling
– fermion masses

Elegant and quite economical description of Nature.
Explains almost everything we observed so far but...

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. . . and Beyond

The Higgs has not yet been observed (in two years we will probably know if it's there).
The Higgs mass is expected to get corrections of the order of the natural cut-off (Planck scale) where new effects are expected. $\rightarrow$ fine-tuning problem

...and Beyond

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In this talk we will consider a model of DEWSB: Minimal Walking Technicolor

$$\text{SU(2) gauge with } \begin{pmatrix} U_L \\ D_L \end{pmatrix}, U_R, D_R \text{ adj} \quad + \quad e^4, \nu^4 \quad + \quad \text{ETC}$$

The unspecified ETC interactions at $\Lambda_{ETC} >> \Lambda_{TC} \approx 1$ TeV can be taken into account at the TC scale through effective 4-fermions interactions:

$$\Delta\mathcal{L} \propto \frac{1}{\Lambda_{ETC}^2}\bar{\Psi}\Psi\bar{\Psi}\Psi, \quad \frac{1}{\Lambda_{ETC}^2}\bar{\Psi}\Psi\bar{\psi}\psi, \quad \frac{1}{\Lambda_{ETC}^2}\bar{\psi}\psi\bar{\psi}\psi$$

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Technicolor

- the techni-quark condensate breaks the EW symmetry
- $SU(2)_L \times U(1)_Y \to U(1)_{EM}$
- Λ_{TC} is tuned to give the right mass to the $W^{\pm}$, Z bosons
- 4-operator coupling $\bar{\Psi}\Psi\bar{\psi}\psi$ to give mass to the SM fermions; effectively generated by some more fundamental theory (*extended technicolor*, ETC) at higher energy Λ_{ETC}
- in general too many technipions exists
- ETC generates also masses for the extra technipions (good!) and flavor changing neutral currents (FCNC, bad!)
- we can require Λ_{ETC} to be high enough in order to suppress FCNC ($\simeq$ 1000 TeV), but then we need an enhancement mechanism to get reasonable masses for the SM fermions

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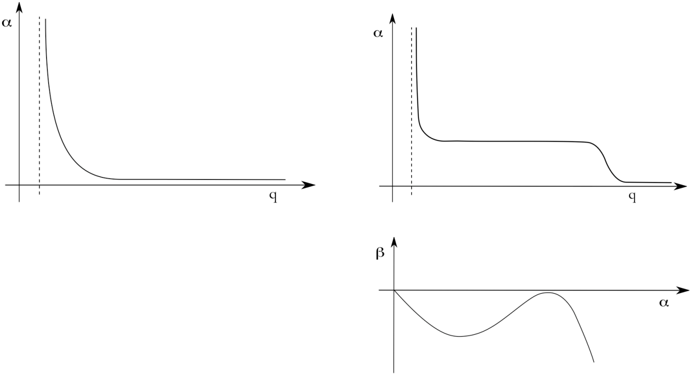
Walking and β-function

Walking needs two separate scales Λ_{ETC} and Λ_{TC}



If the anomalous dimension of the mass γ is large ~ 1, masses for SM particles can be generated.

Why walking

- Taking into account renormalization effects to the operators which generate the quark and lepton masses by TC we have:

$$\langle\bar{\Psi}\Psi\rangle_{ETC} = \langle\bar{\Psi}\Psi\rangle_{TC} \exp\left(\int_{\Lambda_{TC}}^{\Lambda_{ETC}} \frac{\mathrm{d}\mu}{\mu}\gamma(\alpha(\mu))\right)$$

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Why walking

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- For a QCD-like behavior: $\alpha(\mu) \propto 1/\ln(\mu)$, $\gamma \simeq k * \alpha$

$$\langle \bar{\Psi}\Psi \rangle_{ETC} \simeq \langle \bar{\Psi}\Psi \rangle_{TC} \left(\ln \frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{k}$$

- In a *walking* theory: $\alpha \simeq \alpha^*$, $\gamma \simeq \gamma^*$

$$\langle \bar{\Psi}\Psi \rangle_{ETC} \simeq \langle \bar{\Psi}\Psi \rangle_{TC} \left(\frac{\Lambda_{ETC}}{\Lambda_{TC}} \right)^{\gamma^*}$$

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SU(2) with 2 Dirac adjoint fermions

- an (approximate) IR fixed point with large γ is expected near the lower bound of the conformal window (CW)
- even if the strongly interacting TC sector in isolation is inside the CW, ETC interations will deform the theory and the IR fixed point will disappear – in fact this seems even more natural than expecting a near IR fixed point in the isolated TC sector.
- Minimal Walking Technicolor is the theory which lies close to the lower bound of the CW with the smallest naive estimate of the S parameter ($S \simeq \frac{N_D d_R}{6\pi}$)

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Minimal Walking Technicolor

$SU(2) + 1$ Adjoint fermion doublet

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Some simulation details

- HiRep code (Phys. Rev. D 71, (2010) 094503)
- standard Wilson plaquette action
- 2 Dirac Wilson fermions in the adjoint representation
- 1 lattice spacing corresponding to $\beta = 2.25$
- 4 volumes: $16\text{x}8^3$, $24\text{x}12^3$, $32\text{x}16^3$, $64\text{x}24^3$
- Order 5000 configurations for each point.
- measure of the mesonic spectrum, glueball spectrum and string tension

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Deforming the IR-conformal theory with a small mass

$$C(t,g,m,\mu) = \int d^3x \ \langle \Phi_R(t,\mathbf{x})\Phi_R(0)\rangle(g,m,\mu)$$

Weinberg-Callan-Symanzik equation.

$$\left\{ t\frac{\partial}{\partial t} + \beta(g)\frac{\partial}{\partial g} - [1+\gamma(g)]\, m\frac{\partial}{\partial m} + 2\,[d_\Phi - \gamma_\Phi(g)] \right\} C(t,g,m,\mu) = 0$$

$$\mu\frac{dg}{d\mu} = \beta(g)$$

$$\frac{\mu}{m}\frac{dm}{d\mu} = -\gamma(g)$$

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Deforming the IR-conformal theory with a small mass

$$C(t, g, m, \mu) = \int d^3x \, \langle \Phi_R(t, \mathbf{x}) \Phi_R(0) \rangle (g, m, \mu)$$

Weinberg-Callan-Symanzik equation. Close to the fixed point...

$$\left\{ t \frac{\partial}{\partial t} + \beta(g) \frac{\partial}{\partial g} - [1 + \gamma(g)] \, m \frac{\partial}{\partial m} + 2 \left[d_\Phi - \gamma_\Phi(g) \right] \right\} C(t, g, m, \mu) = 0 + \text{corrections}$$

$$\mu \frac{dg}{d\mu} = \beta(g)$$

$$\frac{\mu}{m} \frac{dm}{d\mu} = -\gamma(g)$$

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Deforming the IR-conformal theory with a small mass

$$C(t,g,m,\mu) = \int d^3x \; \langle \Phi_R(t,\mathbf{x}) \Phi_R(0) \rangle (g,m,\mu)$$

Weinberg-Callan-Symanzik equation.

$$\left\{ t\frac{\partial}{\partial t} - [1+\gamma]\, m\frac{\partial}{\partial m} + 2\,[d_\Phi - \gamma_\Phi] \right\} C(t,g,m,\mu) = 0$$

Solution of the Weinberg-Callan-Symanzik equation.

$$C(t,g,m,\mu) \simeq b^{2(d_\Phi-\gamma_\Phi)} C(bt, g_*, b^{-(1+\gamma)} m, \mu) =$$

$$\simeq \mu^{2d_\Phi} \left(\frac{m}{\mu}\right)^{2\frac{d_\Phi-\gamma_\Phi}{1+\gamma}} F\left(tm^{\frac{1}{1+\gamma}}, \mu\right)$$

The mass term breaks the asymptotic scale invariance. A mass gap is expected to be generated.

$$C(t,g,m,\mu) \simeq A \exp\left(-M_\Phi t\right)$$

$$M_\Phi = a_\Phi \mu \left(\frac{m}{\mu}\right)^{\frac{1}{1+\gamma}} \qquad m \to 0$$

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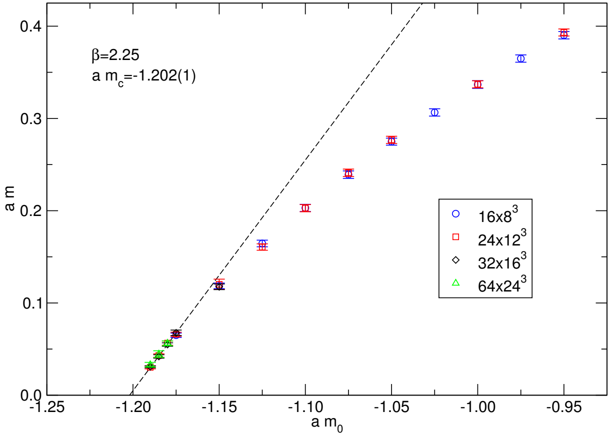
Chiral Limit

The quark mass from the axial Ward identity (PCAC mass) is used.



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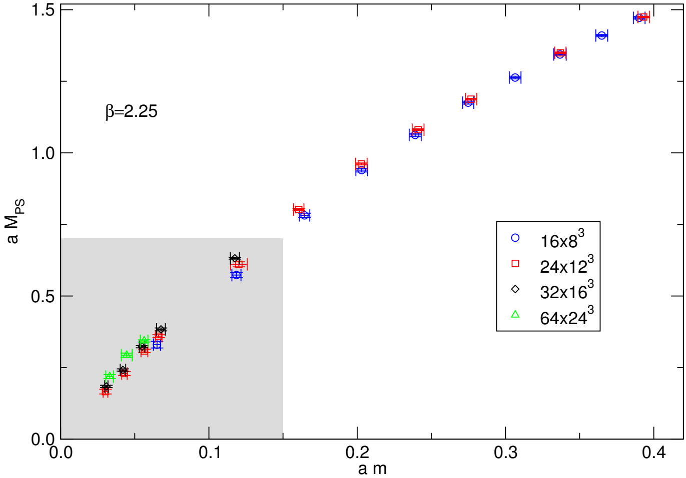
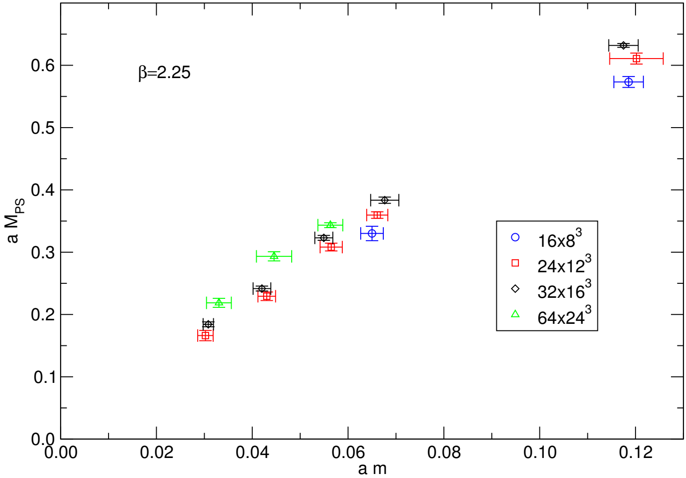
Pseudoscalar Mass



Pseudoscalar Mass



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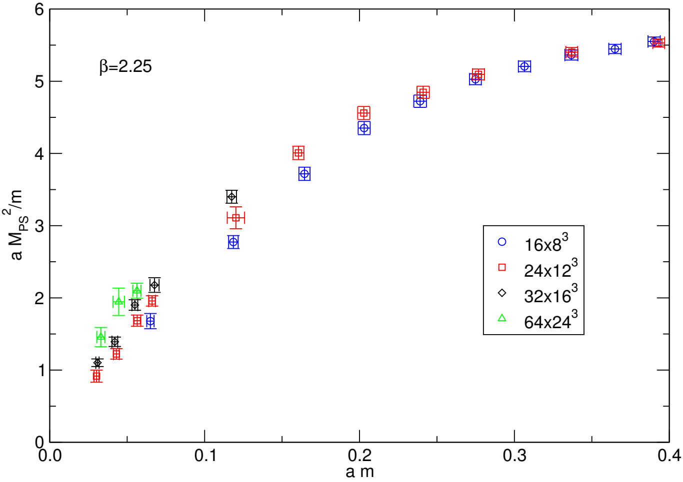
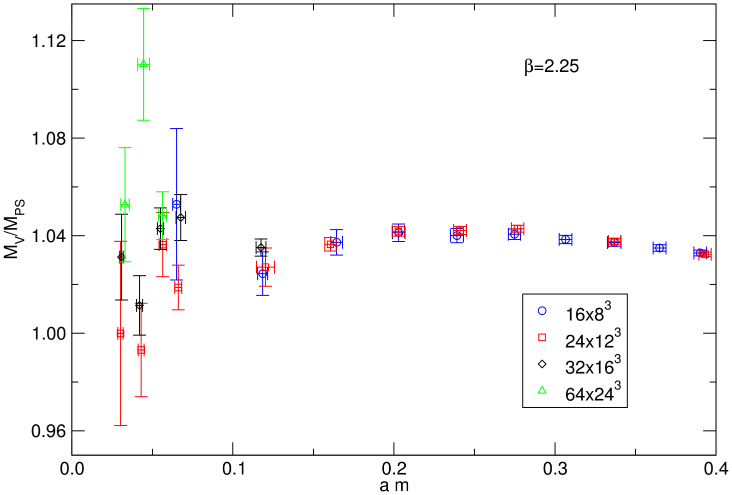
Pseudoscalar Mass



QCD-like → constant, $\gamma^* < 1 \to 0$, $\gamma^* > 1 \to \infty$

Vector over Pseudoscalar



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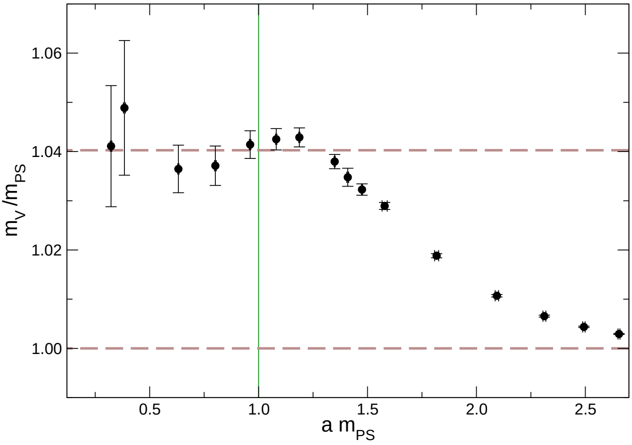
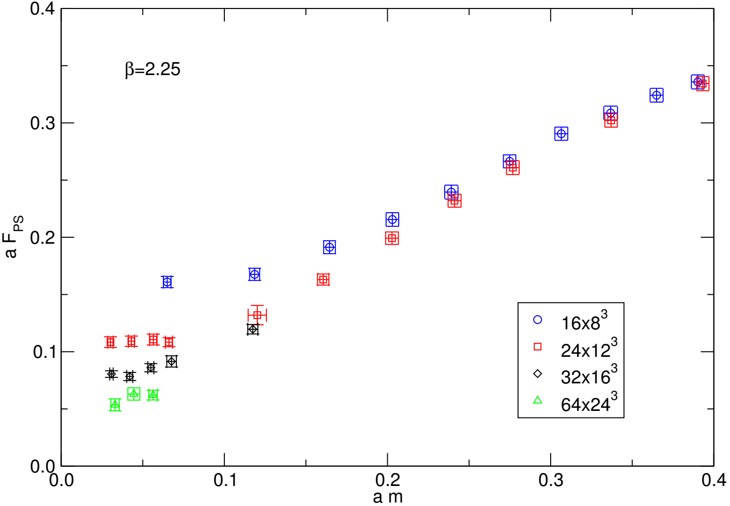
Vector over Pseudoscalar



F_{PS} and finite size scaling



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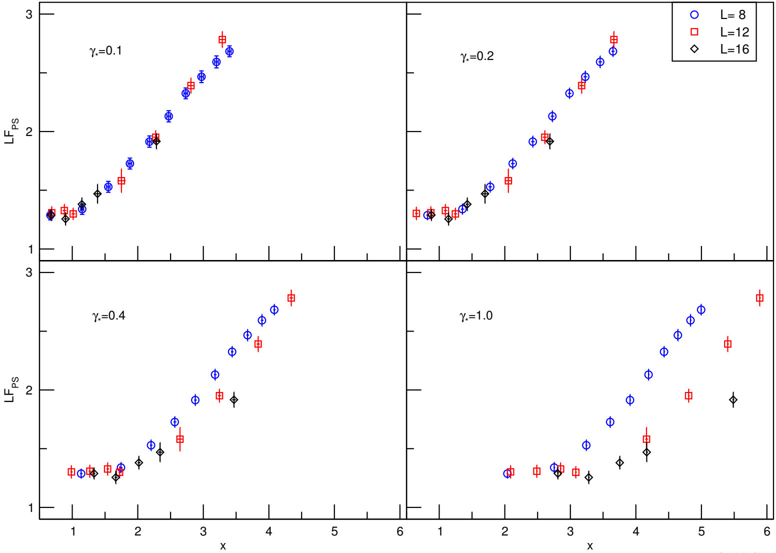
F_{PS} and finite size scaling



$$F_{PS} N_s = f(x) \quad x \equiv N_s m^{1/(1+\gamma^*)}$$

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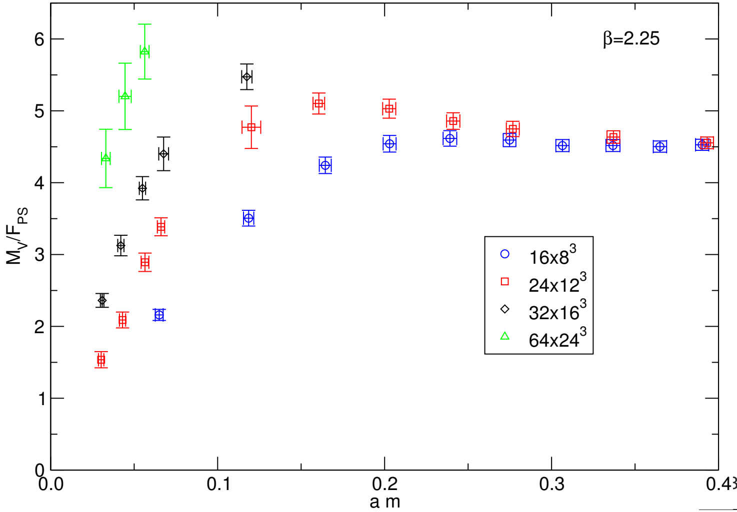
Vector mass and F_{PS}



Conclusion

- Mesonic observables in MWT show evidence for an IR fixed point:
  - scaling of M_{PS} vs. m
  - ratio of M_V/M_{PS} constant
  - FSS of F_{PS}
- $\gamma^* < 1$, our central value is small: ≈ 0.2 (still large systematics)
- Attack the problem from various angles to make sure that the results express truly physical features of the system
  $\hookrightarrow$ better control on systematic errors

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