Precision Electroweak Constraints on Near-Conformal Dynamical EWSB.

Eoin Kerrane

Lattice 2012, Cairns Convention Centre, Queensland.
June 27, 2012

Work with: Luigi Del Debbio, University of Edinburgh.

Outline

Near-conformal DEWSB

- Dynamical EWSB:

$$\mathcal{G}_{\rm SM} \to \mathcal{G}_{\rm TC} \supset \mathcal{G}_{\rm SM}$$

Near-conformal DEWSB

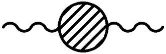
- Dynamical EWSB:

$$\mathcal{G}_{\mathrm{SM}} \rightarrow \mathcal{G}_{\mathrm{TC}} \supset \mathcal{G}_{\mathrm{SM}}$$

- Walking, or near-conformal dynamics thought to help. (*Giedt*, *Tuesday*)

S parameter

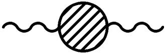
[PT90, PT92]

X, μ  Y, $\nu = ig^{\mu\nu}(\Pi_{XY}(0) + q^2 \Pi'_{XY}(q^2))$

$$S = 16\pi[\Pi'_{33}(0) - \Pi'_{3Q}(0)]$$

S parameter

[PT90, PT92]

X, μ  Y, $\nu = ig^{\mu\nu}(\Pi_{XY}(0) + q^2 \Pi'_{XY}(q^2))$

$$S = 16\pi[\Pi'_{33}(0) - \Pi'_{3Q}(0)]$$

- Experimental constraint: $S = 0.03 \pm 0.09$[N+10]

Theoretical Estimates

[PT90, PT92]

- 1st order PT:

$$S \simeq \frac{1}{6\pi}\left(\frac{N_\mathrm{f}\, d(R)}{2}\right)$$

- Dispersive integral:

$$S \simeq 0.3\frac{N_\mathrm{f}}{2}\frac{d(R)}{3}$$

Theoretical Estimates

[PT90, PT92]

- 1st order PT:

$$S \simeq \frac{1}{6\pi}\left(\frac{N_{\mathrm{f}} d(R)}{2}\right)$$

- Dispersive integral:

$$S \simeq 0.3 \frac{N_{\mathrm{f}}}{2}\frac{d(R)}{3}$$

- Suggested to be suppressed in near-conformal models [AS99].

On the Lattice

$$S = 4\pi \frac{N_f}{2} [\Pi'_{VV}(0) - \Pi'_{AA}(0)]$$

On the Lattice

$$S = 4\pi \frac{N_{\mathrm{f}}}{2} [\Pi'_{\mathrm{VV}}(0) - \Pi'_{\mathrm{AA}}(0)]$$

- In QCD: Overlap [S$^+$08], and Domain-Wall [BDDWZ09] calculations.

On the Lattice

$$S = 4\pi \frac{N_{\mathrm{f}}}{2}[\Pi'_{\mathrm{VV}}(0) - \Pi'_{\mathrm{AA}}(0)]$$

- In QCD: Overlap [S+08], and Domain-Wall [BDDWZ09] calculations.
- Domain-Wall calculation in $SU(3)$ with $N_{\mathrm{f}} = 2, 6$ fundamental fermions [A+11].

Outline

Minimal Walking Technicolor

- MWT: $SU(2)$ theory with $N_{\mathrm{f}} = 2$ fermions in adjoint representation.

Minimal Walking Technicolor

- MWT: $SU(2)$ theory with $N_{\mathrm{f}} = 2$ fermions in adjoint representation.
- Agreed to be inside conformal window [DDLP+10].

Minimal Walking Technicolor

- MWT: $SU(2)$ theory with $N_{\mathrm{f}} = 2$ fermions in adjoint representation.
- Agreed to be inside conformal window [DDLP+10].
- No first-principles non-perturbative estimate of S.

Minimal Walking Technicolor

- MWT: $SU(2)$ theory with $N_{\mathrm{f}} = 2$ fermions in adjoint representation.
- Agreed to be inside conformal window [DDLP+10].
- No first-principles non-perturbative estimate of S.
- 1st order PT:

$$S \simeq \frac{1}{6\pi}\left(\frac{N_{\mathrm{f}} d(R)}{2}\right) \simeq 0.16$$

- Dispersive integral:

$$S \simeq 0.3 \frac{N_{\mathrm{f}}}{2}\frac{d(R)}{3} \simeq 0.3$$

Simulation Details

- Builds on Wilson simulations used for spectroscopy etc. [DDLP+10].
- One coupling: $\beta = 2.25$, two volumes 32×16^3, 64×24^3, several masses.

Simulation Details

- Builds on Wilson simulations used for spectroscopy etc. [DDLP+10].
- One coupling: $\beta = 2.25$, two volumes 32×16^3, 64×24^3, several masses.
- Use a mixed-action simulation, with Domain-Wall valence quarks.

Simulation Details

- Builds on Wilson simulations used for spectroscopy etc. [DDLP+10].
- One coupling: $\beta = 2.25$, two volumes 32×16^3, 64×24^3, several masses.

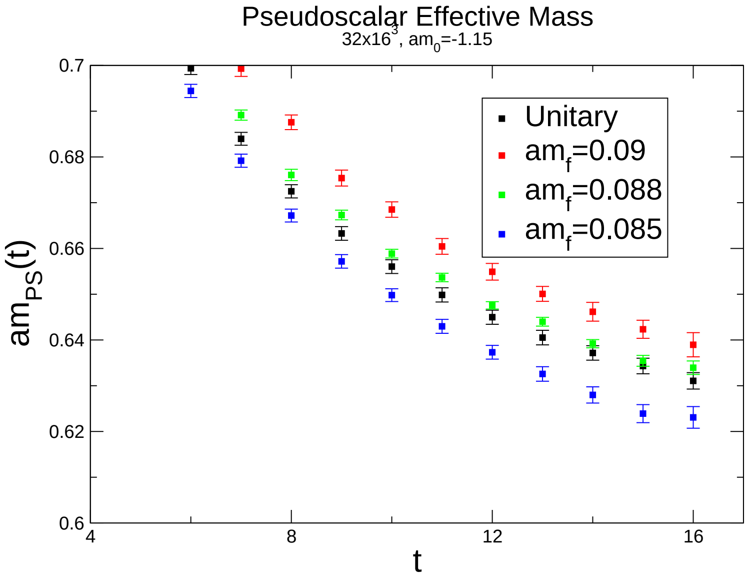
- Use a mixed-action simulation, with Domain-Wall valence quarks.
- Must tune bare DWF mass to reproduce unitary Wilson observables.

Simulation Details

- Builds on Wilson simulations used for spectroscopy etc. [DDLP+10].
- One coupling: $\beta = 2.25$, two volumes 32×16^3, 64×24^3, several masses.

- Use a mixed-action simulation, with Domain-Wall valence quarks.
- Must tune bare DWF mass to reproduce unitary Wilson observables.
- Tune via m_{PS}, mostly on smaller volume.

Tuning


Pseudoscalar Effective Mass
32x16^3, am$_0$=-1.15
$am_{PS}(t)$
t
0.6
0.62
0.64
0.66
0.68
0.7
4
8
12
16
Unitary
am_f=0.09
am_f=0.088
am_f=0.085

Residual Chiral Symmetry Breaking.

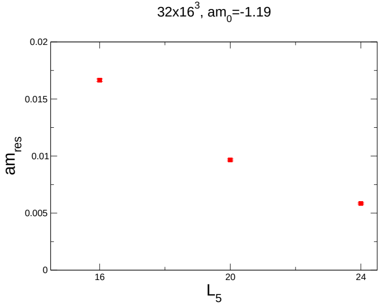
$$m_{\mathrm{res}}(t) = \frac{\sum_{\vec{x}} \langle J^a_{5\mathrm{q}}(\vec{x}, t) J^a_5(0) \rangle}{2 \sum_{\vec{x}} \langle J^a_5(\vec{x}, t) J^a_5(0) \rangle}$$

[FS95]

Residual Chiral Symmetry Breaking.

$$m_{\mathrm{res}}(t) = \frac{\sum_{\vec{x}} \langle J^a_{5\mathrm{q}}(\vec{x}, t) J^a_5(0) \rangle}{2 \sum_{\vec{x}} \langle J^a_5(\vec{x}, t) J^a_5(0) \rangle}$$

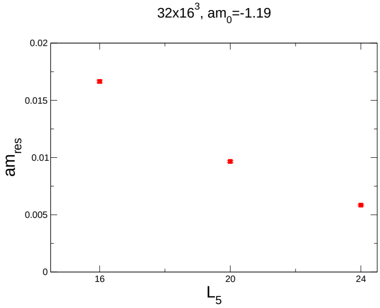
[FS95]



Residual Chiral Symmetry Breaking.

$$m_{\mathrm{res}}(t) = \frac{\sum_{\vec{x}} \langle J^a_{5\mathrm{q}}(\vec{x}, t) J^a_5(0) \rangle}{2 \sum_{\vec{x}} \langle J^a_5(\vec{x}, t) J^a_5(0) \rangle}$$

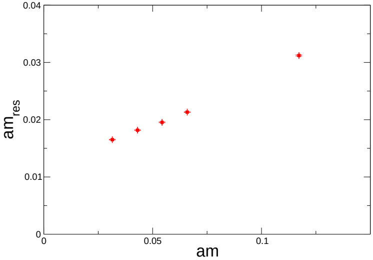
[FS95]



- All following data computed at $L_5 = 16$.

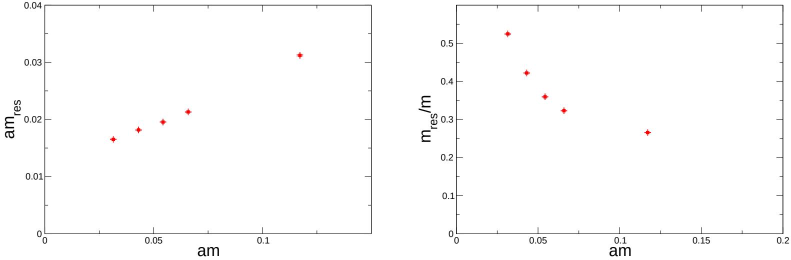
Residual Mass

- We note the behaviour of $m_{\rm res}$ in the chiral limit.



Residual Mass

- We note the behaviour of m_{res} in the chiral limit.



Outline

Two-point functions

$$\Pi^{\mathcal{J}}_{\mu\nu}(\bar{q}) = Z_{\mathrm{J}} \sum_{\mathbf{x}} e^{iq\cdot x} \langle \mathcal{J}(\mathbf{x}) J(0) \rangle$$

$$\Pi^{J}_{\mu\nu}(\bar{q}) = Z_{\mathrm{J}}^2 \sum_{\mathbf{x}} e^{iq\cdot x} \langle J(\mathbf{x}) J(0) \rangle$$

$$\Pi^{\mathcal{V}-\mathcal{A}}_{\mu\nu} = \Pi^{\mathcal{V}}_{\mu\nu} - \Pi^{\mathcal{A}}_{\mu\nu}$$

$$\Pi^{V-A}_{\mu\nu} = \Pi^{V}_{\mu\nu} - \Pi^{A}_{\mu\nu}$$

Ward Identities

$$\Pi_{\mu\nu}(\bar{q}) = (\bar{q}^2\delta_{\mu\nu} - \bar{q}_\mu\bar{q}_\nu)\Pi_{\mathrm{T}}(\bar{q}^2) + \bar{q}_\mu\bar{q}_\nu\Pi_{\mathrm{L}}(\bar{q}^2)$$

Ward Identities

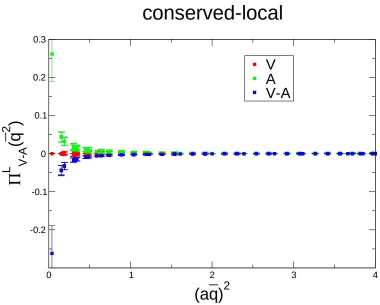
$$\Pi_{\mu\nu}(\bar{q}) = (\bar{q}^2\delta_{\mu\nu} - \bar{q}_\mu\bar{q}_\nu)\Pi_{\mathrm{T}}(\bar{q}^2) + \bar{q}_\mu\bar{q}_\nu\Pi_{\mathrm{L}}(\bar{q}^2)$$

$$\bar{q}_\mu e^{\frac{iq_\mu a}{2}}\Pi^{\mathcal{V}}_{\mu\nu} = 0$$

Ward Identities

$$\Pi_{\mu\nu}(\bar{q}) = (\bar{q}^2\delta_{\mu\nu} - \bar{q}_\mu\bar{q}_\nu)\Pi_{\mathrm{T}}(\bar{q}^2) + \bar{q}_\mu\bar{q}_\nu\Pi_{\mathrm{L}}(\bar{q}^2)$$

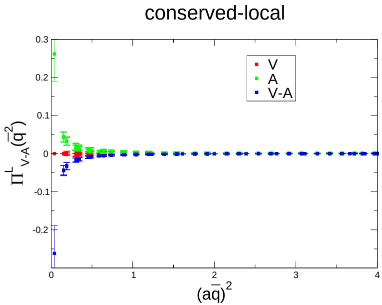
$$\bar{q}_\mu e^{\frac{iq_\mu a}{2}}\Pi^{\mathcal{V}}_{\mu\nu} = 0$$

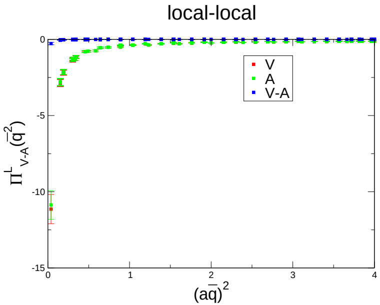


Ward Identities

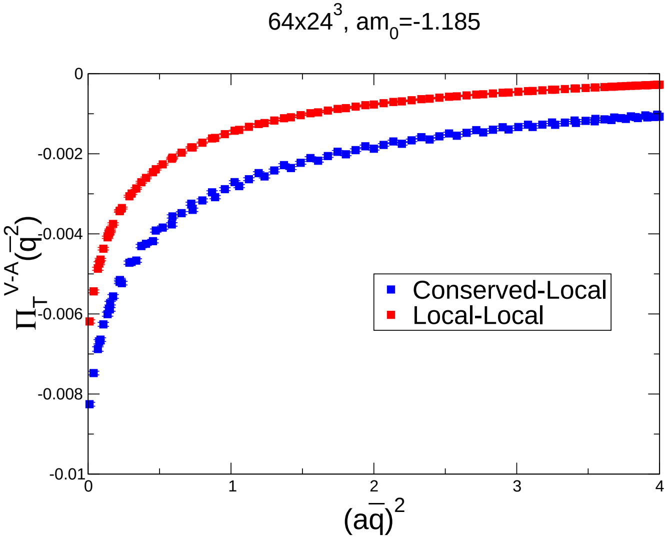
$$\Pi_{\mu\nu}(\bar{q}) = (\bar{q}^2\delta_{\mu\nu} - \bar{q}_\mu\bar{q}_\nu)\Pi_{\mathrm{T}}(\bar{q}^2) + \bar{q}_\mu\bar{q}_\nu\Pi_{\mathrm{L}}(\bar{q}^2)$$

$$\bar{q}_\mu e^{\frac{iq_\mu a}{2}}\Pi^{\mathcal{V}}_{\mu\nu} = 0$$

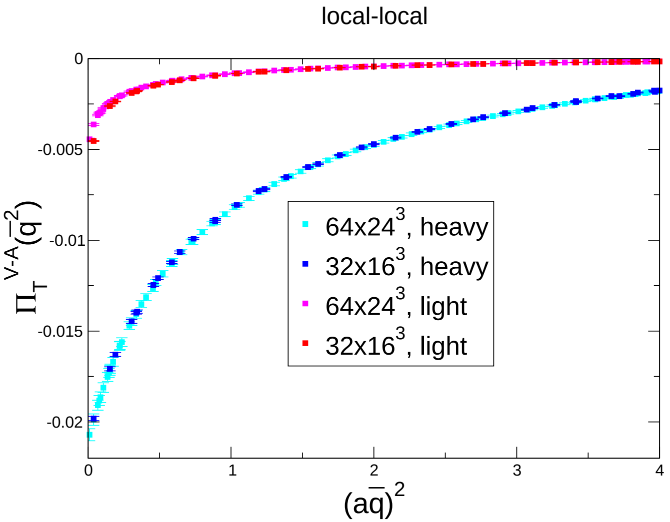




Transverse Vacuum Polarisation.



Transverse Vacuum Polarisation



Outline

Extracting S

$$S = 4\pi \frac{d}{d(a\bar{q})^2} a^2 \Pi_{\mathrm{T}}^{V-A}(\bar{q}^2) - \Delta S_{\mathrm{SM}}$$

Extracting S

$$S = 4\pi \frac{d}{d(a\bar{q})^2} a^2 \Pi_{\mathrm{T}}^{V-A}(\bar{q}^2) - \Delta S_{\mathrm{SM}}$$

$$\Delta S_{\mathrm{SM}} = \frac{1}{12\pi} \int_0^\infty \frac{ds}{s} \left\{ 1 - \left(1 - \frac{m_{\mathrm{H}}^2}{s}\right)^3 \theta(s - m_{\mathrm{H}}^2) \right\}$$

Extracting S

$$S = 4\pi \frac{d}{d(a\bar{q})^2} a^2 \Pi_{\mathrm{T}}^{V-A}(\bar{q}^2) - \Delta S_{\mathrm{SM}}$$

$$\Delta S_{\mathrm{SM}} = \frac{1}{12\pi} \int_0^\infty \frac{ds}{s} \left\{ 1 - \left(1 - \frac{m_{\mathrm{H}}^2}{s}\right)^3 \theta(s - m_{\mathrm{H}}^2) \right\}$$

- $m_{\mathrm{H}} = m_{\mathrm{V}}$, $\int_0^\infty ds \to \int_{4m_{\mathrm{PS}}^2}^\infty$ [A+11]

Extracting S

$$S = 4\pi \frac{d}{d(a\bar{q})^2} a^2 \Pi_{\mathrm{T}}^{V-A}(\bar{q}^2) - \Delta S_{\mathrm{SM}}$$

$$\Delta S_{\mathrm{SM}} = \frac{1}{12\pi} \int_0^\infty \frac{ds}{s} \left\{ 1 - \left(1 - \frac{m_{\mathrm{H}}^2}{s}\right)^3 \theta(s - m_{\mathrm{H}}^2) \right\}$$

- $m_{\mathrm{H}} = m_{\mathrm{V}}$, $\int_0^\infty ds \to \int_{4m_{\mathrm{PS}}^2}^\infty$ [A+11]
- $\frac{m_{\mathrm{V}}}{m_{\mathrm{PS}}} \simeq 1$, $\Rightarrow \Delta S_{\mathrm{SM}} \ll 1$ [DDLP+10].

Fitting

- Fit using Pade approximants: $P[M,N](x) = \frac{\sum_{i=0}^{M} a_i x^i}{1+\sum_{j=1}^{N} b_j x^j}$

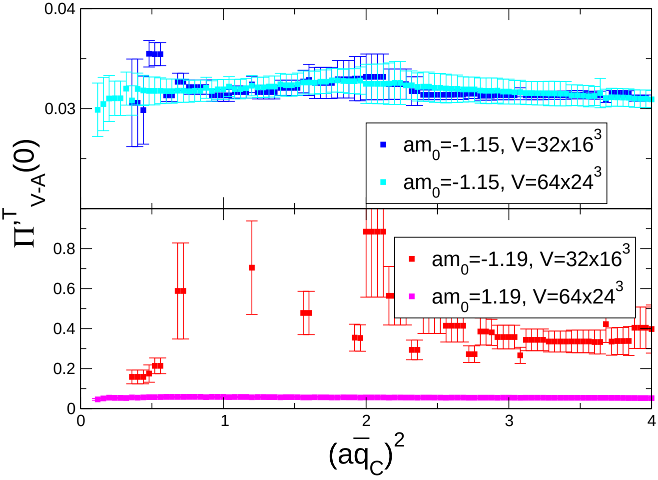
Fitting

- Fit using Pade approximants: $P[M,N](x) = \frac{\sum_{i=0}^{M} a_i x^i}{1+\sum_{j=1}^{N} b_j x^j}$
- Vary fit range $[0, (a\bar{q}_C)^2]$.

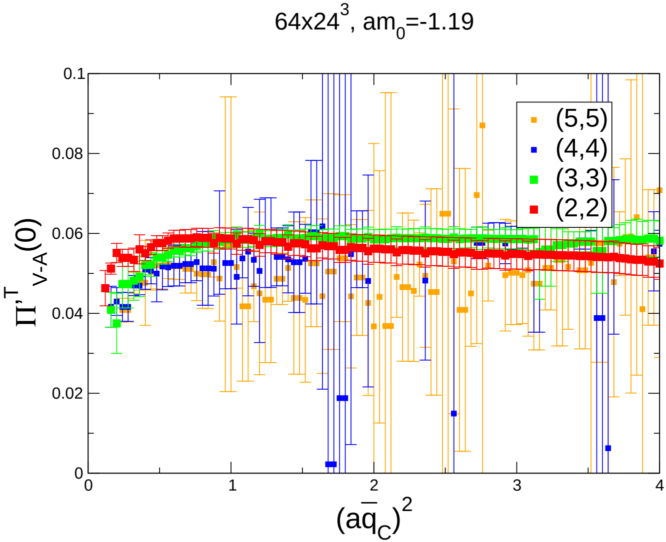
Fitting

- Fit using Pade approximants: $P[M,N](x) = \frac{\sum_{i=0}^{M} a_i x^i}{1+\sum_{j=1}^{N} b_j x^j}$
- Vary fit range $[0, (a\bar{q}_C)^2]$.
- Restrict to $M = N$, and vary M in $2 \ldots 5$ [ABGP12]

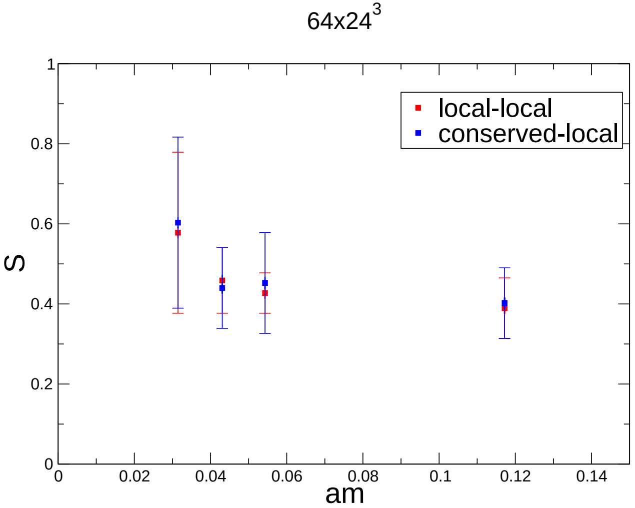
Impact of Large Volume



Choice of Fit Ansatz



Provisional Results



Outline

Conclusions

- Obtain a result for MWT S parameter contribution, with certain caveats.
- Must extend to lower m_{res} in order to be more reliable.
- Systematics of tuning, Z, fit ansatz should be improved.

Conclusions

- Obtain a result for MWT S parameter contribution, with certain caveats.
- Must extend to lower m_{res} in order to be more reliable.
- Systematics of tuning, Z, fit ansatz should be improved.

Thanks very much.

Thomas Appelquist et al.
Parity Doubling and the S Parameter Below the Conformal Window.
Phys.Rev.Lett., 106:231601, 2011.

Christopher Aubin, Thomas Blum, Maarten Golterman, and Santiago Peris.
Model-independent parametrization of the hadronic vacuum polarization and g-2 for the muon on the lattice.
2012.

Thomas Appelquist and Francesco Sannino.
The Physical Spectrum of Conformal SU(N) Gauge Theories.
Phys. Rev., D59:067702, 1999.

Peter A. Boyle, Luigi Del Debbio, Jan Wennekers, and James M. Zanotti.
The S Parameter in QCD from Domain Wall Fermions.
2009.

Luigi Del Debbio, Biagio Lucini, Agostino Patella, Claudio Pica, and Antonio Rago.
Mesonic spectroscopy of Minimal Walking Technicolor.
Phys. Rev., D82:014509, 2010.

Vadim Furman and Yigal Shamir.
Axial symmetries in lattice QCD with Kaplan fermions.
Nucl. Phys., B439:54–78, 1995.

K. Nakamura et al.
Review of particle physics.
J.Phys.G, G37:075021, 2010.

Michael Edward Peskin and Tatsu Takeuchi.
A New constraint on a strongly interacting Higgs sector.
Phys. Rev. Lett., 65:964–967, 1990.

Michael Edward Peskin and Tatsu Takeuchi.
Estimation of oblique electroweak corrections.
Phys. Rev., D46:381–409, 1992.

E. Shintani et al.

S-parameter and pseudo-Nambu-Goldstone boson mass from lattice QCD.
Phys. Rev. Lett., 101:242001, 2008.

Twisted Boundary Conditions