On the flavor dependence of m_ϱ / f_π

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Context

- Strongly interacting extensions of Standard Model
- Composite Higgs (f_0 or σ)
- Non-trivial new particle prediction: ϱ vector
- How well can m_ϱ differentiate between models?

Motivation

How well can m_ϱ differentiate between models?

- Gauge group G, representation R, flavor number N_f
- Lattice prediction for dimensionless ratios m_ϱ / f_π
- $f_\pi = 246\, GeV$, m_ϱ should be experimentally measured in GeV
- Main question: what is the model dependence of m_ϱ / f_π?

Motivation

Previous lattice results in various $SU(3)$ models:

$m_\varrho / f_\pi \sim 8$ not much N_f or R dependence

Jin/Mawhinney 0910.3216 1304.0312

LatKMI 1302.6859

LSD 1312.5298 1601.04027 1807.08411

LatHC 0907.4562 1209.0391 1605.08750 1601.03302

But no controlled infinite volume and continuum and chiral extrapolation. (Except QCD but $m \neq 0$)

Goal

Fully controlled results with $SU(3)$, $R = fund$ and $N_f = 2, 3, 4, 5, 6$

$$L/a \to \infty \qquad m \to 0 \qquad a \to 0$$

Outline

- Finite volume effects m_π, f_π
- Finite volume effects m_ϱ
- Chiral-continuum extrapolation
- KSRF relation, $g_{\varrho\pi\pi}$
- $SU(N)$, N-dependence
- Conclusion

Lattice setup

$SU(3)$ gauge group, Symanzik tree level improved gauge action, staggered stout-improved fermion action

At each N_f: 4 lattice spacing, 4 masses for each lattice spacing: 16 points

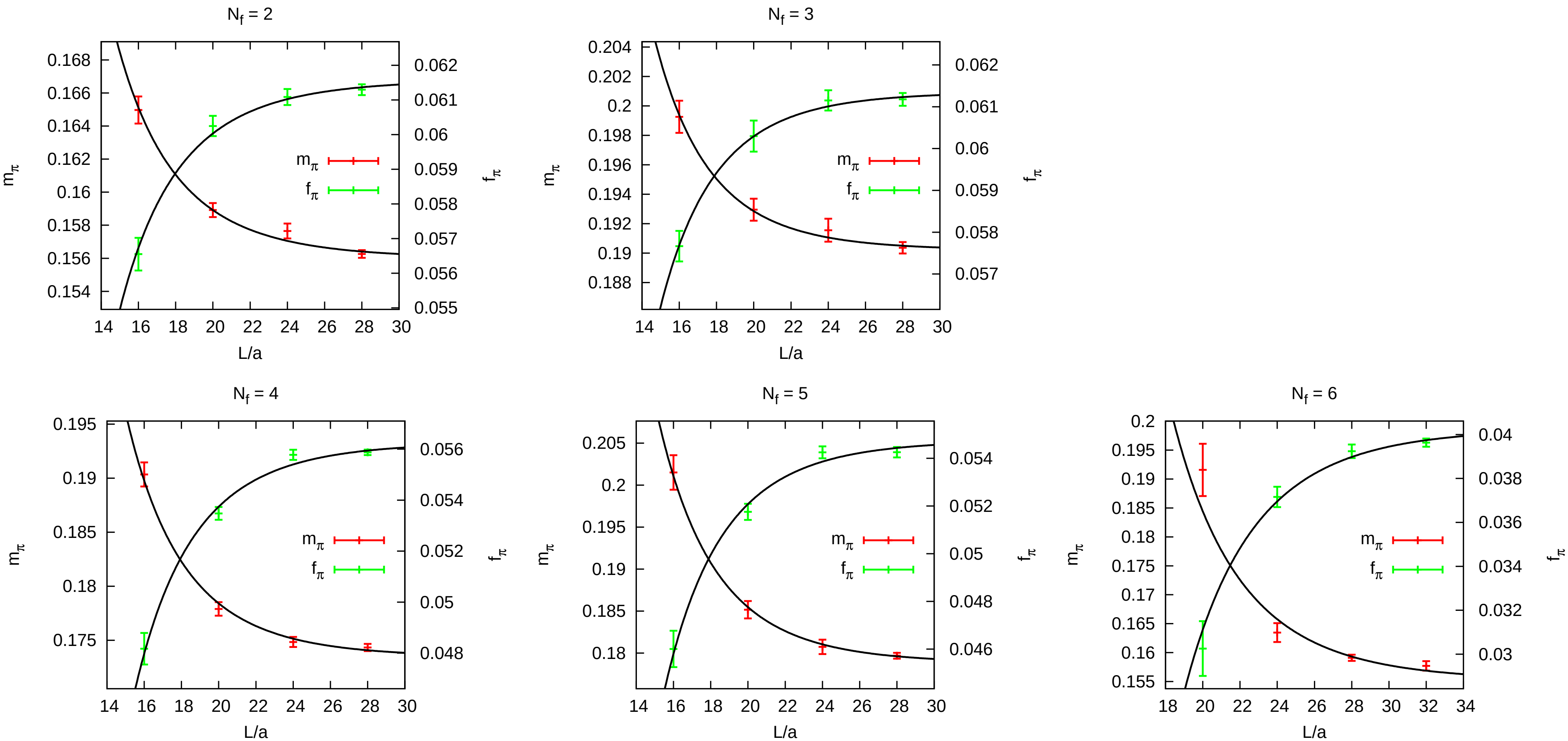
Finite volume effects - m_π, f_π

Exponential finite volume effects for m_π, f_π

How large does $m_\pi L$ needs to be to have less than 1% finite volume effect?

Simulations at fixed β, m for each N_f at 4 L/a

Finite volume effects - m_π, f_π



Functional form: Gasser-Leutwyler

Finite volume effects - m_π, f_π

$$m_\pi L > 3.10 + 0.35\ N_f$$

For 1% finite volume effects on m_π, f_π

For example $N_f = 6$: $\quad m_\pi L > 5.20$

Finite volume effects - m_ϱ

m_ϱ is different: $\varrho \to \pi\pi$ resonance, need in finite volume

$$\frac{m_\varrho}{2m_\pi} < \sqrt{1 + \left(\frac{2\pi}{m_\pi L}\right)^2}$$

Finite volume effects from full Luscher

Fits to finite volume energy levels $E(m_\varrho, g_{\varrho\pi\pi}, L)$ or $E(m_\varrho, \Gamma_\varrho, L)$

If just one volume L: obtain $g_{\varrho\pi\pi}$ a posteriori from KSRF relation (see later)

Check finite volume effect on m_ϱ a posteriori

Taste breaking

$O(a^2)$ scaling of taste broken Goldstones from $\chi = \frac{\langle Q^2 \rangle}{V}$

$\longrightarrow$ backup slides if interested :)

Systematics

- Volumes large enough
- Mass small enough
- Lattice spacing small enough

$\longrightarrow$ chiral - continuum extrapolation of $m_\varrho w_0$ and $f_\pi w_0$

Chiral - continuum extrapolation

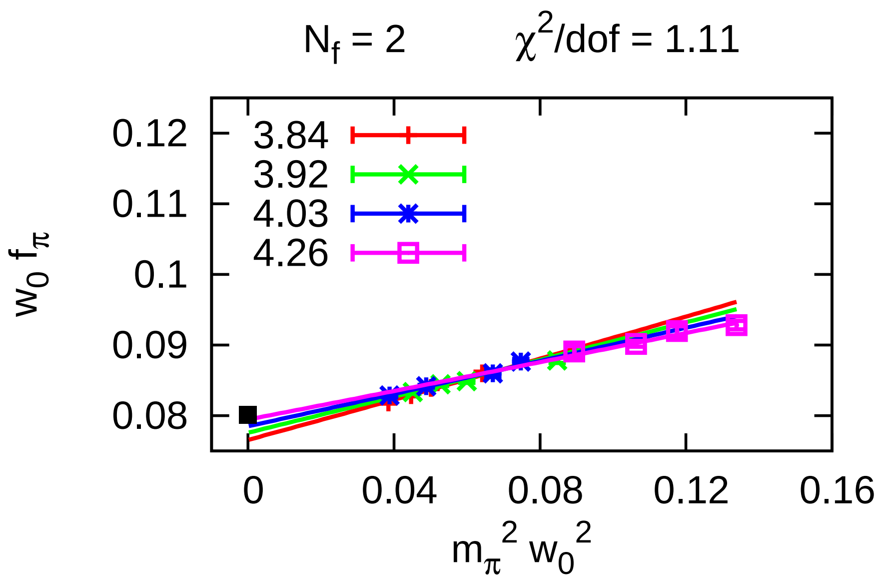
Global fit

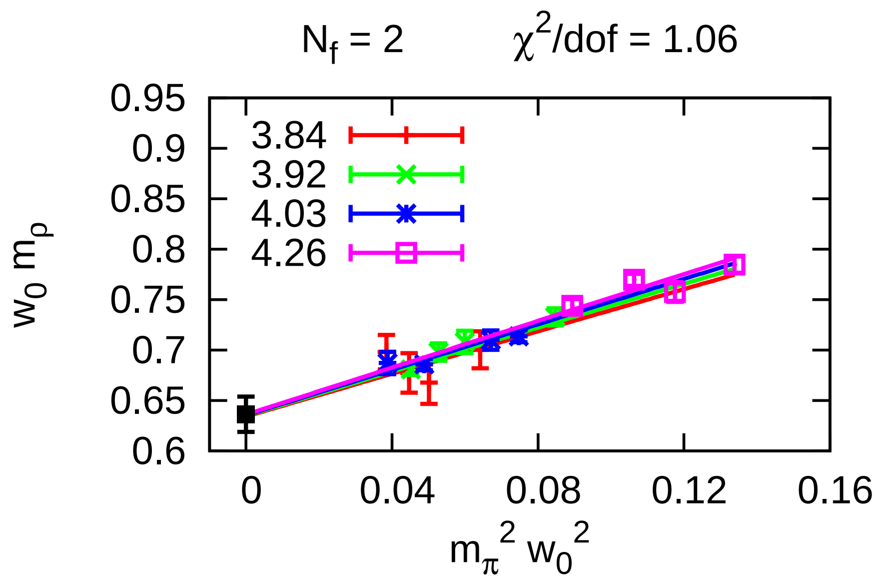
$$Xw_0 = C_0 + C_1 m_\pi^2 w_0^2 + C_2 \frac{a^2}{w_0^2} + C_3 \frac{a^2}{w_0^2} m_\pi^2 w_0^2$$

$X = m_\varrho, f_\pi$

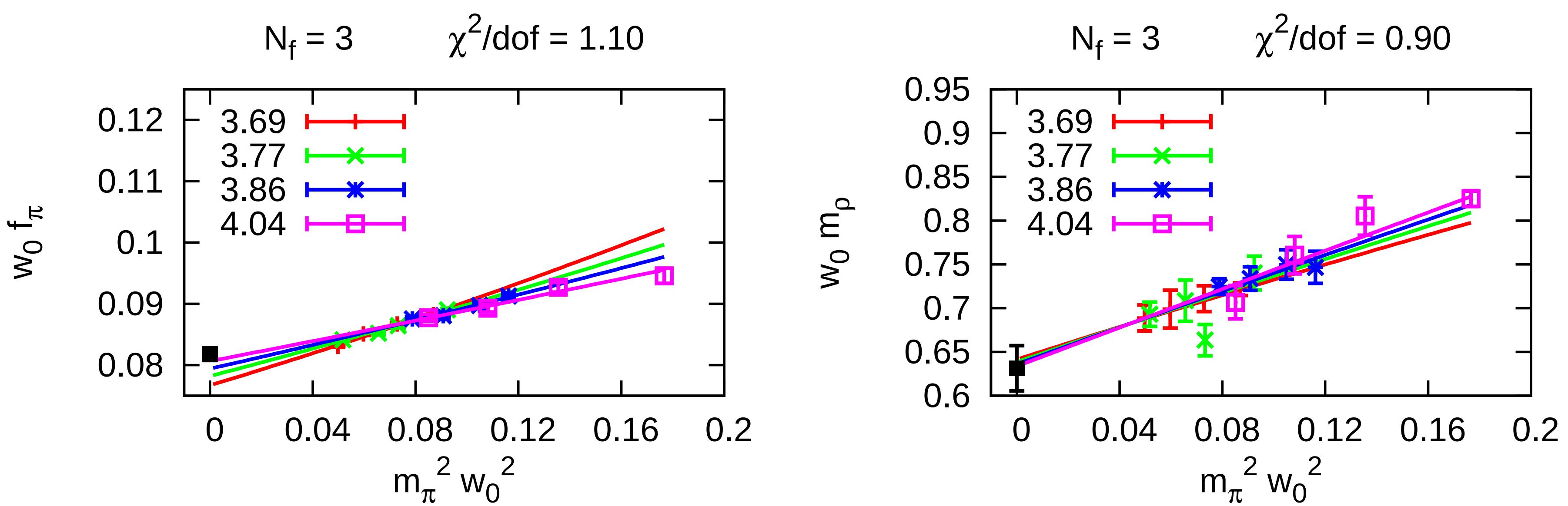
At each N_f: 16 points, dof = 14

Chiral - continuum, $N_f = 2$

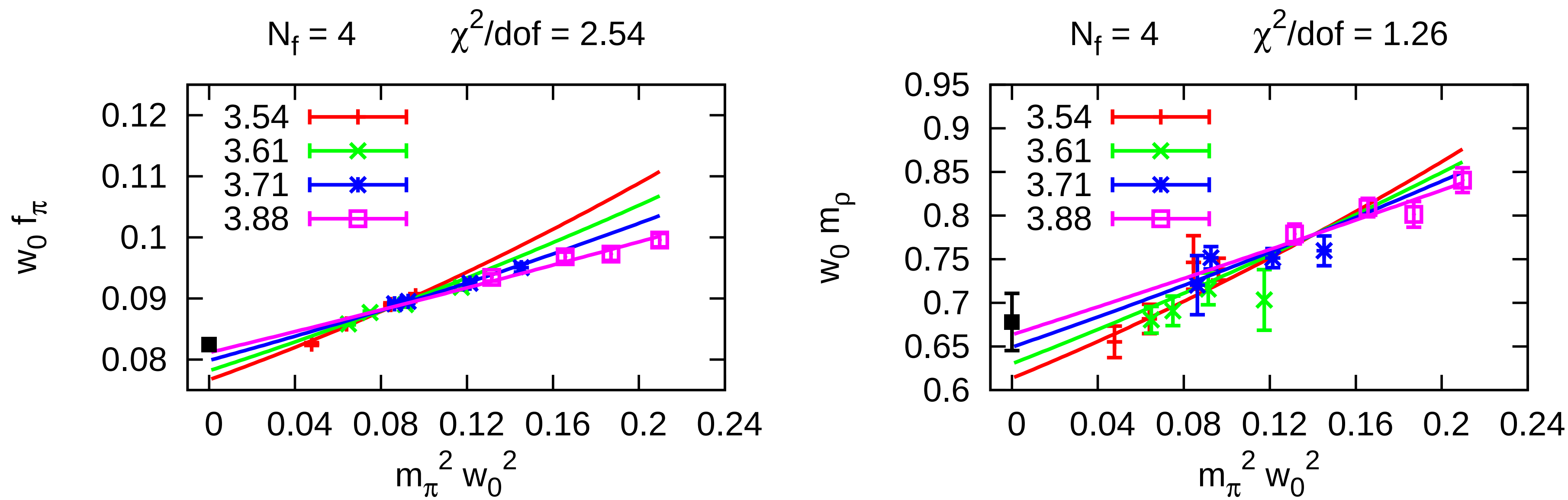




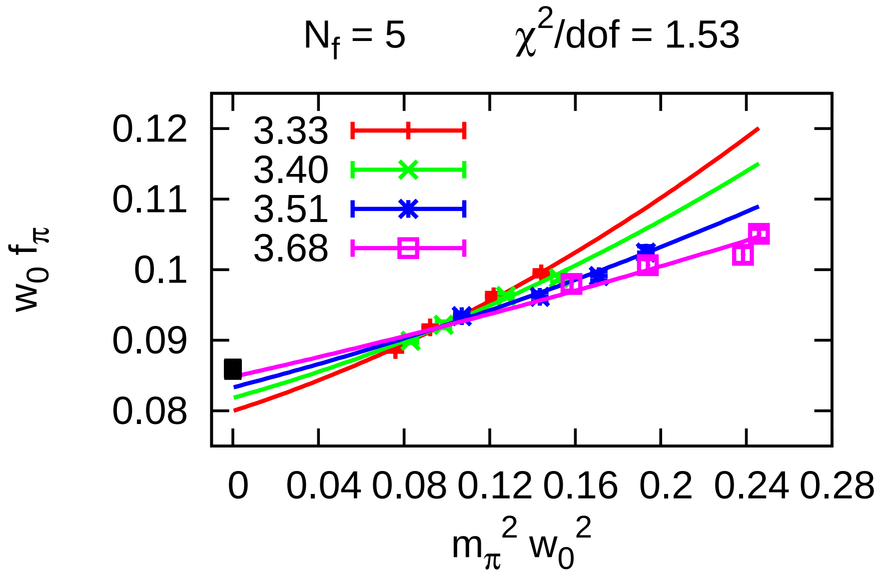
Chiral - continuum, $N_f = 3$

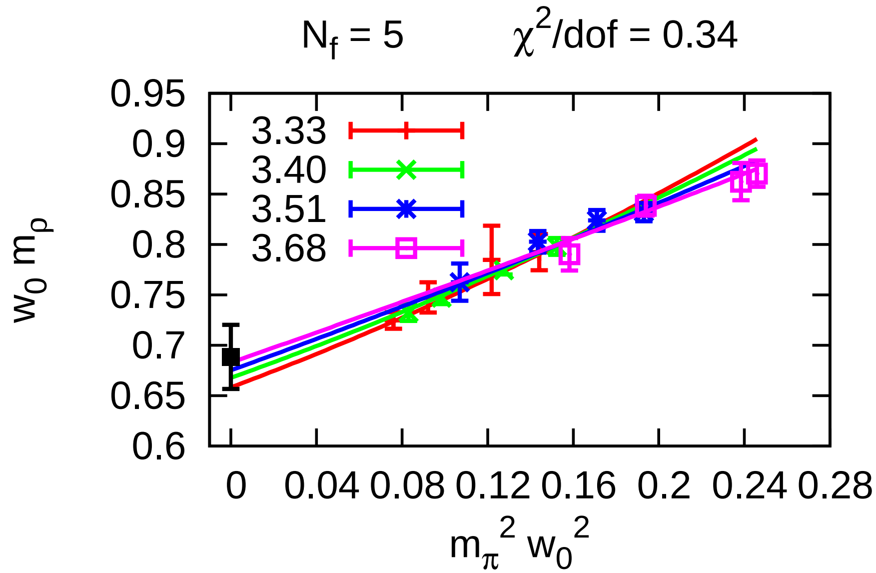


Chiral - continuum, $N_f = 4$

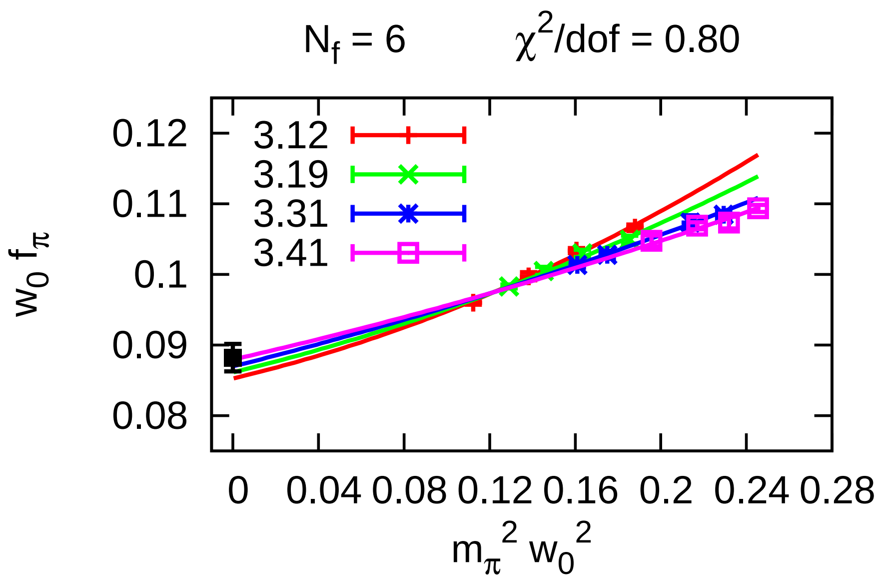


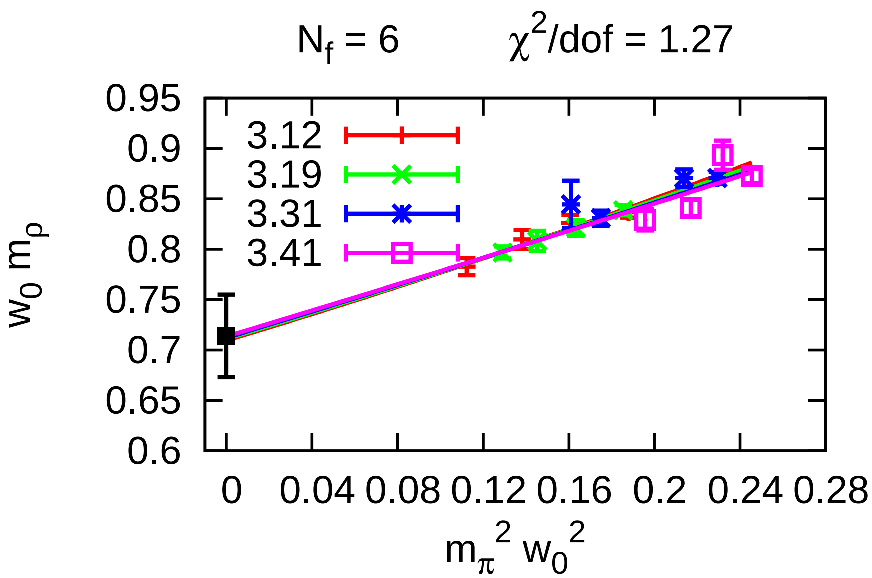
Chiral - continuum, $N_f = 5$



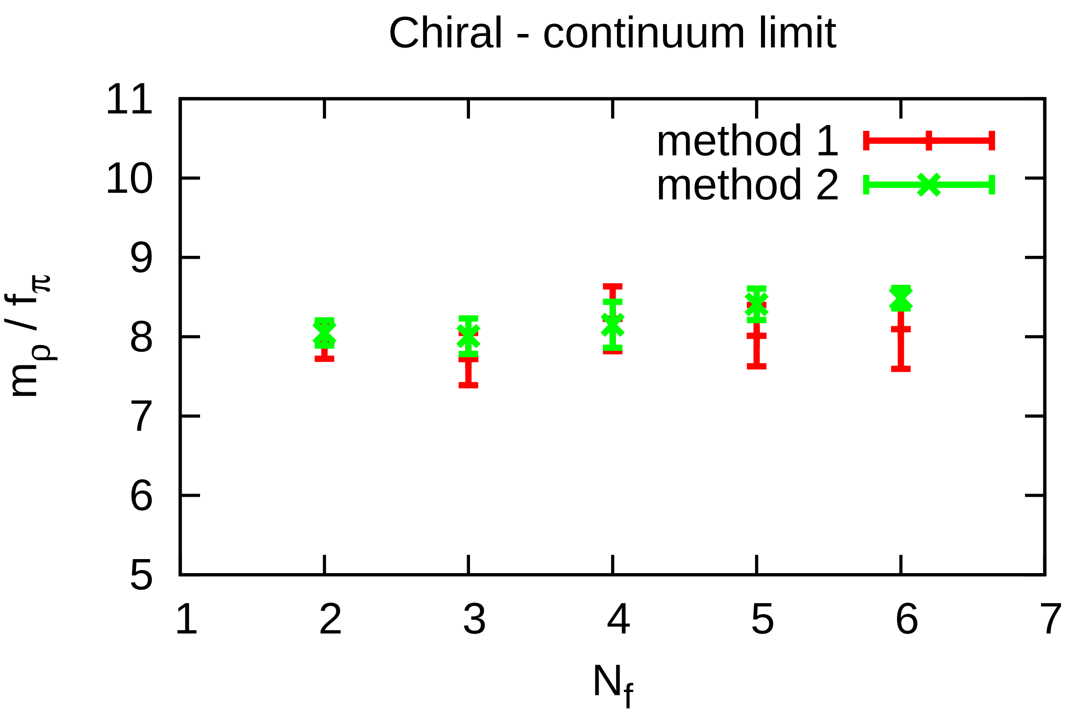


Chiral - continuum, $N_f = 6$





Chiral-continuum for ratio m_ϱ / f_π



Constant fit with method 1

$$\frac{m_\varrho}{f_\pi} = 7.95(15) \text{ with } \chi^2/dof = 0.26$$

Method 2 compatible (cross-check)

Conclusion

No statistically significant N_f-dependence!

KSRF-relations

$$g_{\varrho\pi\pi} = \frac{m_\varrho}{f_\varrho} = \sqrt{48\pi\frac{\Gamma_\varrho}{m_\varrho}} = \frac{1}{\sqrt{2}}\frac{m_\varrho}{f_\pi}$$

Quite precise in QCD, should be more precise in $m \to 0$ limit

We have m_ϱ/f_π, assume KSRF $\to$ we have $g_{\varrho\pi\pi}$

$g_{\varrho\pi\pi}$ also N_f-independent ~ 5.62

Go back to $E(m_\varrho, g_{\varrho\pi\pi}, L)$ full Luscher $\to$ finite volume effects on m_ϱ small a posteriori

KSRF-relations

Assuming KSRF many ϱ related quantities are N_f-independent:

- $g_{\varrho\pi\pi}$
- $\Gamma_\varrho / m_\varrho$
- m_ϱ / f_ϱ

Looks like vector meson doesn't know anything about N_f

Gauge group dependence

Large-N: $m_\varrho/f_\pi \sim 1/\sqrt{N}$

- $SU(2)$: $m_\varrho \sim 2.4\ TeV$
- $SU(3)$: $m_\varrho \sim 2.0\ TeV$
- $SU(4)$: $m_\varrho \sim 1.7\ TeV$
- $SU(5)$: $m_\varrho \sim 1.5\ TeV$
- $SU(6)$: $m_\varrho \sim 1.4\ TeV$

Projects for $SU(N \neq 3)$ people

Is m_ϱ/f_π also N_f-independent for $SU(N)$?

$SU(2)$ $\quad R = fund$: $N_f = 2, 3, 4, 5$?

Lewis/Pica/Sannino 1109.3513

Arthur/Drach/Hansen/Hietanen/Pica/Sannino 1602.06559

Drach/Janowski/Pica 1710.07218

Amato/Leino/Rummukainen/Tuominen/Tahtinen 1806.07154

$SU(4)$ $\quad R = fund$: $N_f = 2, 3, 4, 5, 6\ldots$

Conclusions and outlook

- Dynamics very N_f-dependent
- But: $m_\varrho / f_\pi = 7.95(15)$ for $SU(3)$ and $1 < N_f < 7$
- KSRF: $g_{\varrho\pi\pi}$ also N_f-independent (entire vector meson sector)
- Experimental result for m_ϱ: conclude about $SU(N)$ not R, N_f
- Theoretical understanding of KSRF?
  Proven in SQCD — Komargodski 1010.4105
- Theoretical understanding of N_f-independence?
- $SU(3)$ with $N_f > 6$
- $SU(2)$ and $SU(4)$

Thank you for your attention!

Taste breaking

One could measure all taste broken Goldstones directly

Instead: look for a quantity with the most N_f-dependence and see if it is reproduced or not

Good candidate: topological susceptibility $\chi = \frac{\langle Q^2 \rangle}{V}$, very sensitive to light degrees of freedom

Continuum: $\chi = \frac{m_\pi^2 f_\pi^2}{2N_f}$

Taste breaking

Chiral - continuum extrapolate χ, see N_f-dependence

Extrapolation in w_0 units (dof=13)

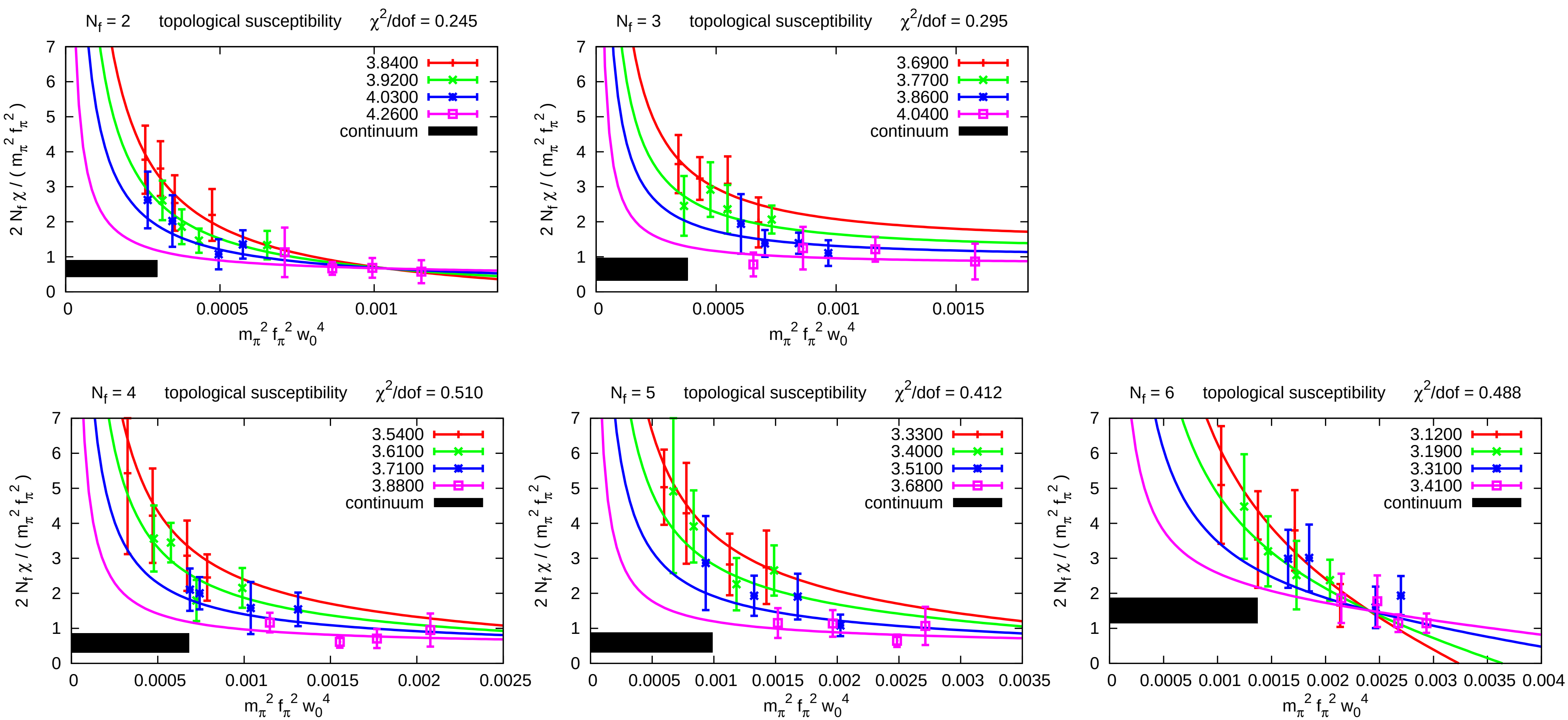
$$\chi w_0^4 = C_0 m_\pi^2 f_\pi^2 w_0^4 + C_1 \frac{a^2}{w_0^2} + C_2 \frac{a^2}{w_0^2}(m_\pi^2 f_\pi^2 w_0^4)$$

Continuum expectation: $C_0 = \frac{1}{2N_f}$

But taste broken Goldstones also enter χ

Billeter/Detar/Osborn hep-lat/0406032

Taste breaking - topological susceptibility



$\frac{2N_f\chi}{m_\pi^2 f_\pi^2}$ as a function of $m_\pi^2 f_\pi^2 w_0^4$ (should be 1)