The S-parameter with Many Fermions on the Lattice

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on behalf of the LSD Collaboration

arXiv:1009.5967 (PRL, in press)

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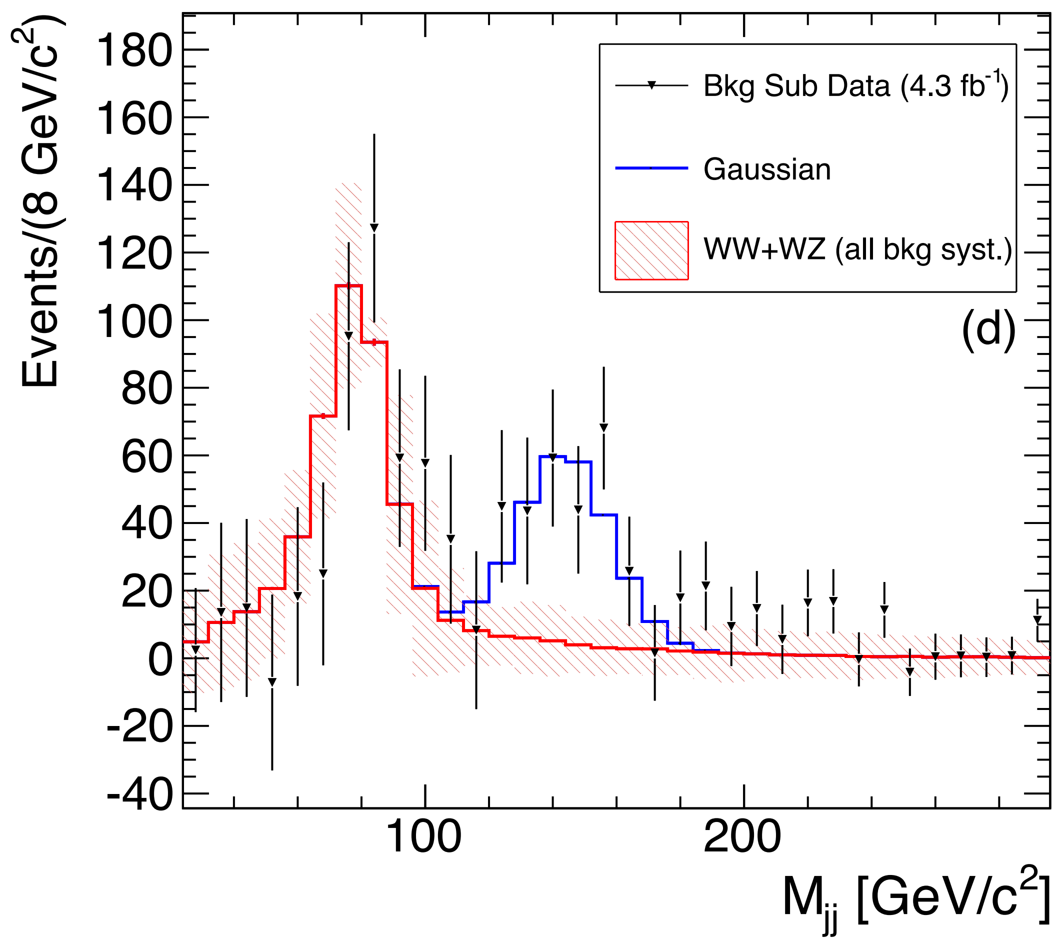
Motivation

- With the LHC fully operational, we may be on the verge of discovering BSM physics (and there are already some possible hints!)

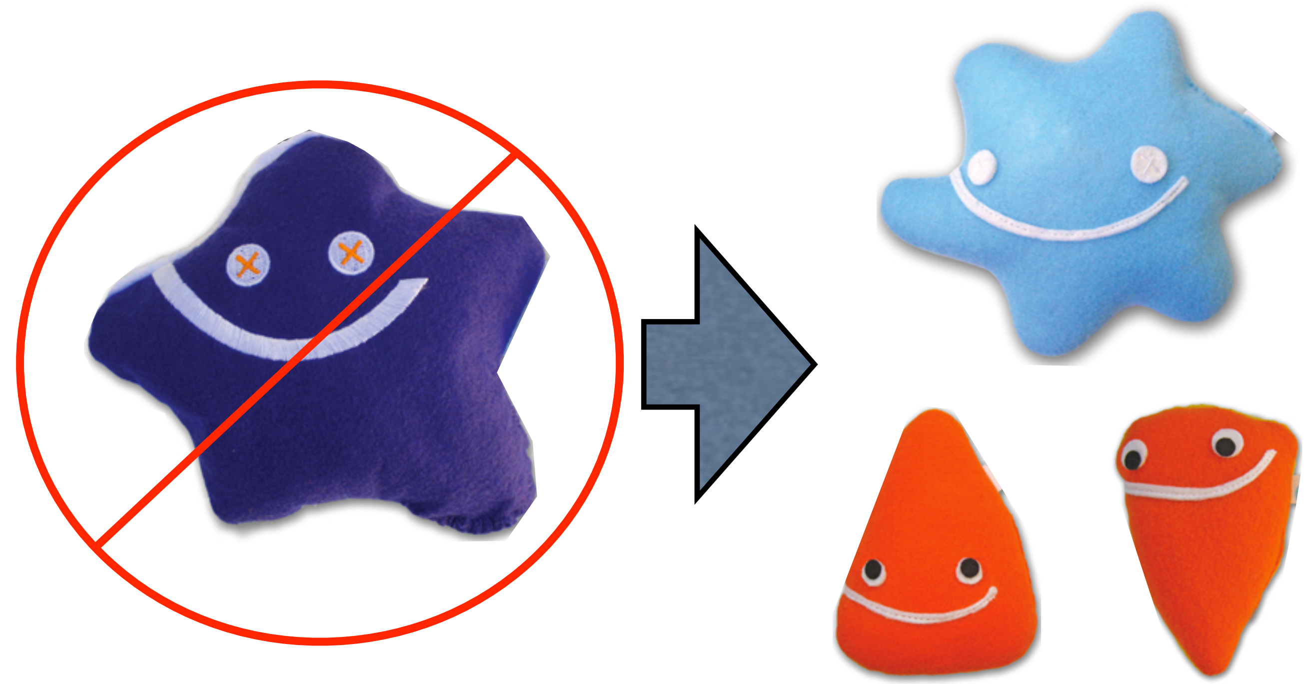
- New physics could easily be strongly coupled, in which case lattice will likely have a large role to play - generalized toolset for exploration of non-perturbative dynamics.



(arXiv:1104.0699)

One example: technicolor

- Technicolor theories replace the Higgs scalar field with new strong dynamics. Chiral symmetry breaking also breaks electroweak symmetry.



http://particlezoo.net

- Minimal or one-doublet technicolor is QCD, rescaled:

$$\Lambda_{QCD} \sim 1 \text{ GeV} \rightarrow \Lambda_{TC} \sim 1 \text{ TeV}.$$

- Generically, technicolor models are in tension with precision EW, especially the *S*-parameter:

$$S \simeq 0.25 \frac{N_{TF}}{2} \frac{N_{TC}}{3} + \frac{1}{12\pi} \left(\frac{N_{TF}^2}{4} - 1 \right) \log \left(\frac{m_{\rho_T}^2}{m_{\pi_T}^2} \right)$$

(experiment: *S*=0 or slightly negative)

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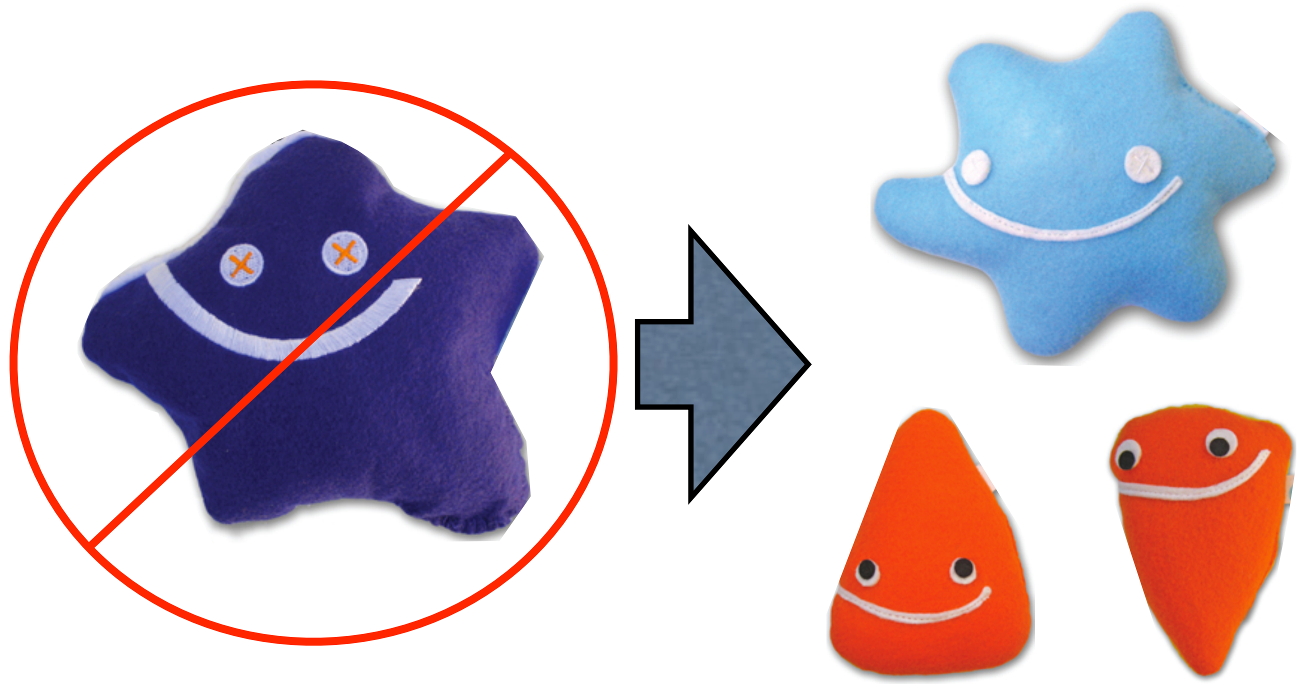

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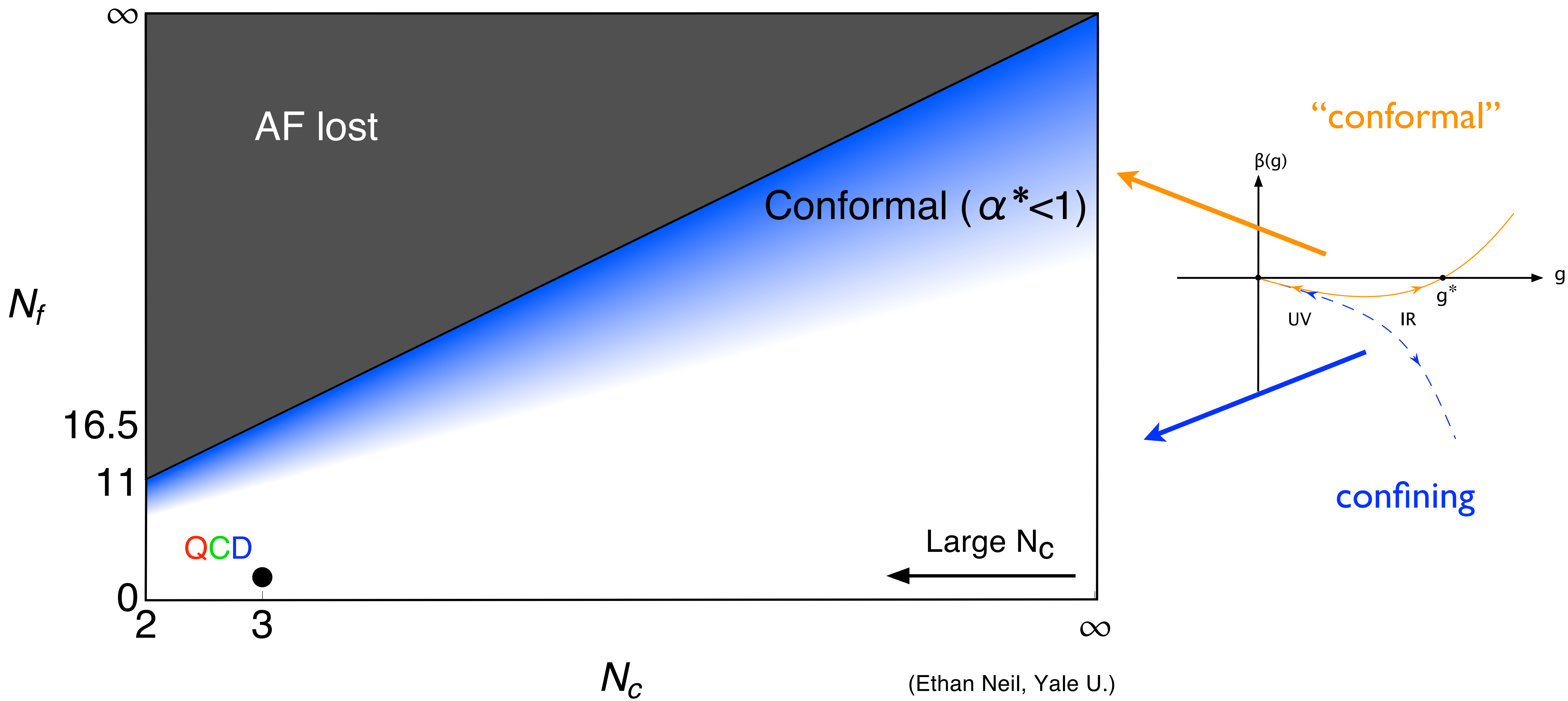
relies on QCD pheno!

(experiment: *S*=0 or slightly negative)

A roadmap in N_c and N_f



Large N_c expansion works well for QCD, but for large N_f, things change drastically (IR fixed point.)

Lattice can be applied anywhere with AF!

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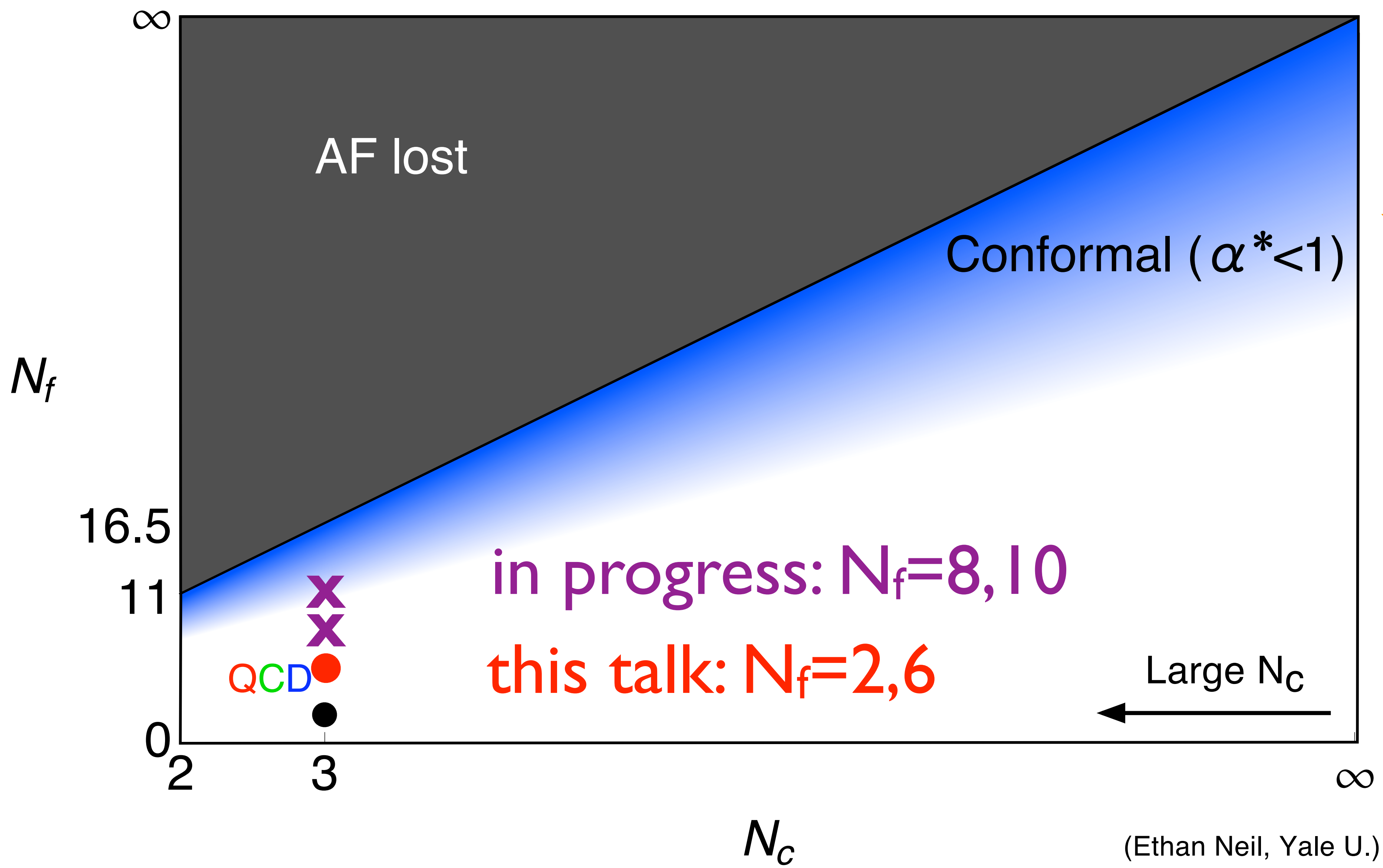

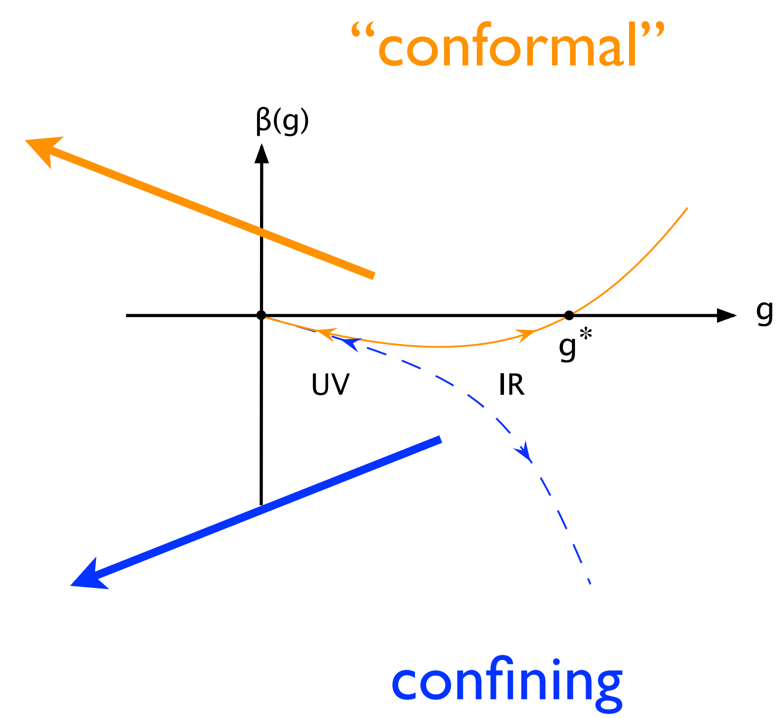

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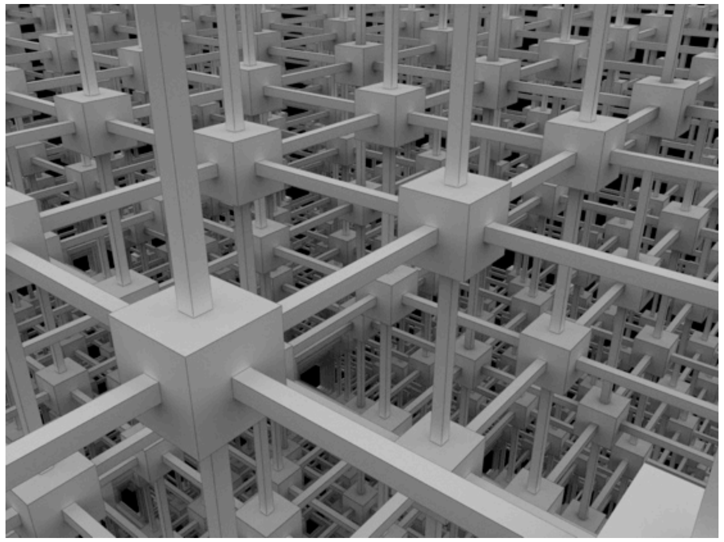
Going to the Lattice

$$\langle \mathcal{O} \rangle = \frac{1}{\mathcal{Z}} \int \mathcal{D}U \mathcal{D}\overline{\psi} \mathcal{D}\psi \; \mathcal{O}(U, \overline{\psi}, \psi) \exp\left(-S[U, \overline{\psi}, \psi]\right)$$



$$\langle \mathcal{O} \rangle = \frac{1}{N} \sum_{U \in \mathcal{U}} \langle \mathcal{O} \rangle_U$$

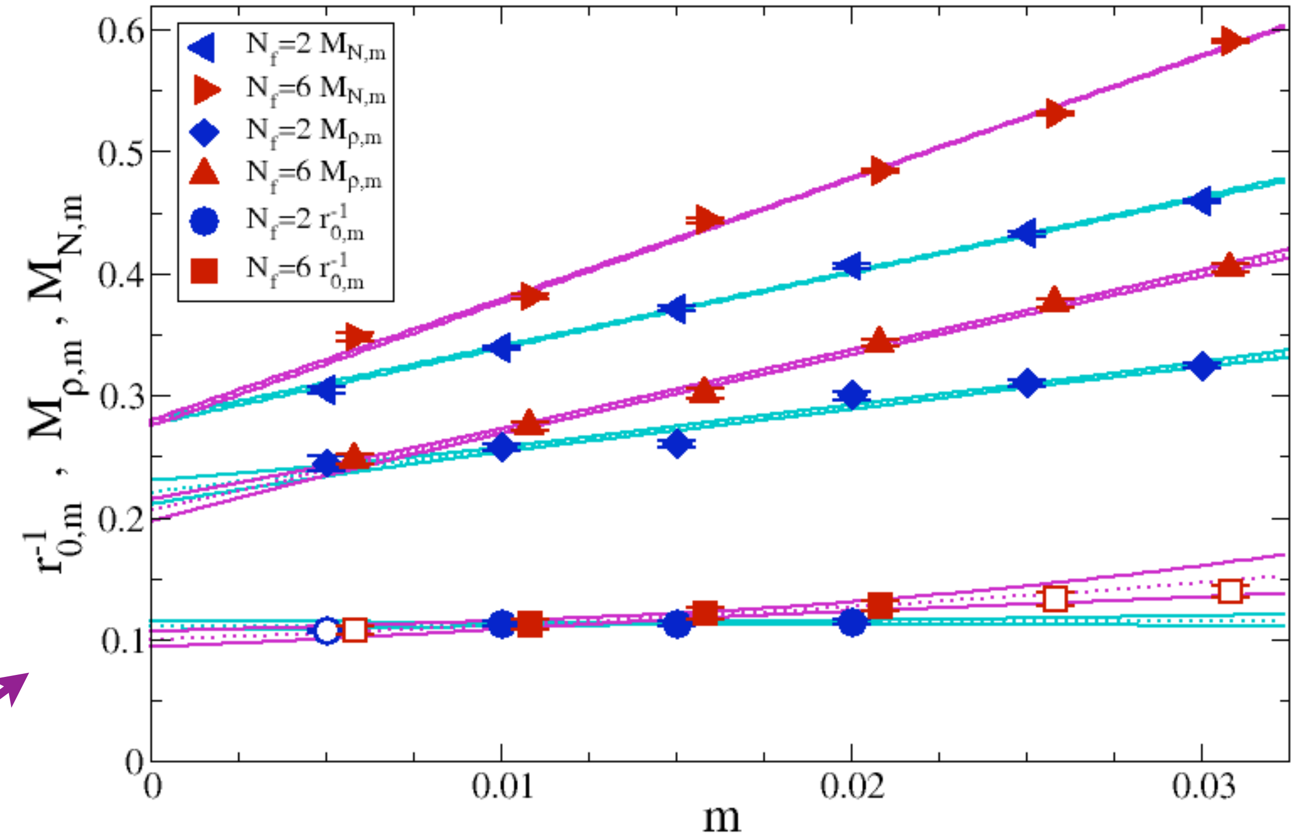
Discretize to make the path integral finite-dimensional (but sharply peaked!)

Importance sampling and Monte Carlo techniques give us an ensemble of field configurations, weighted by exp(-S)

Most of the computational cost is in ensemble generation, so measure many different <O>

Lattice Ensembles

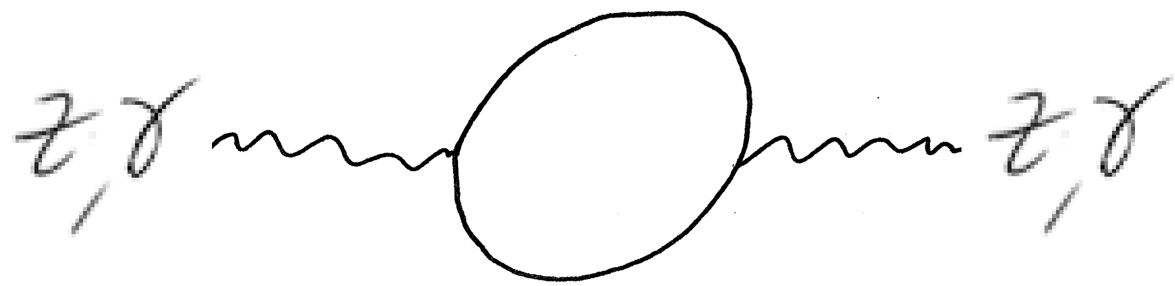
- This talk: two sets of ensembles with N_f=2,6 fermions (all with mass *m*)
- Ensembles are tuned to hold IR scale(s) fixed in chiral limit
- Goldstone mass kept small compared to box size



	$N_f = 2$		$N_f = 6$	
am_f	"M_π"L	N_{cfg}	"M_π"L	N_{cfg}
0.005	3.5	1430	4.7	1350
0.010	4.4	2750	5.4	1250
0.015	5.3	1060	6.6	550
0.020	6.5	720	7.8	400
0.025	7.0	600	8.8	420
0.030	7.8	400	9.8	360

S-parameter

S is sensitive to electroweak "oblique corrections", i.e. vacuum polarization of EW gauge bosons. Can express using V/A currents:



$$S = -4\pi(\Pi'_{VV}(0) - \Pi'_{AA}(0))$$

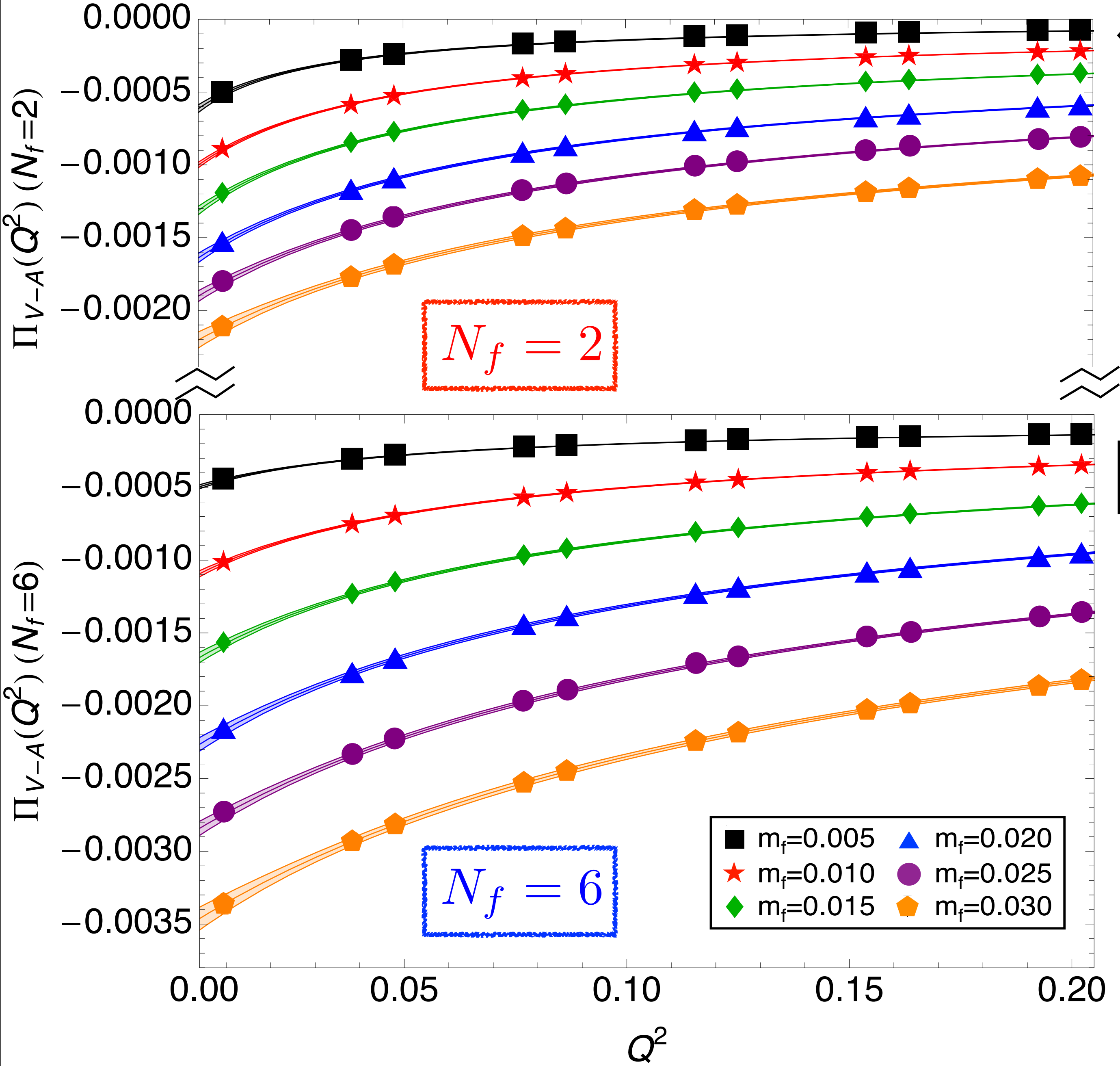
<u>Overview of lattice measurement:</u>

- Measure VV, AA correlators on chosen ensembles
- Fit to Pade-(m,n) approximants:
- Extract slope of (VV-AA) at zero q^2, convert to S-parameter

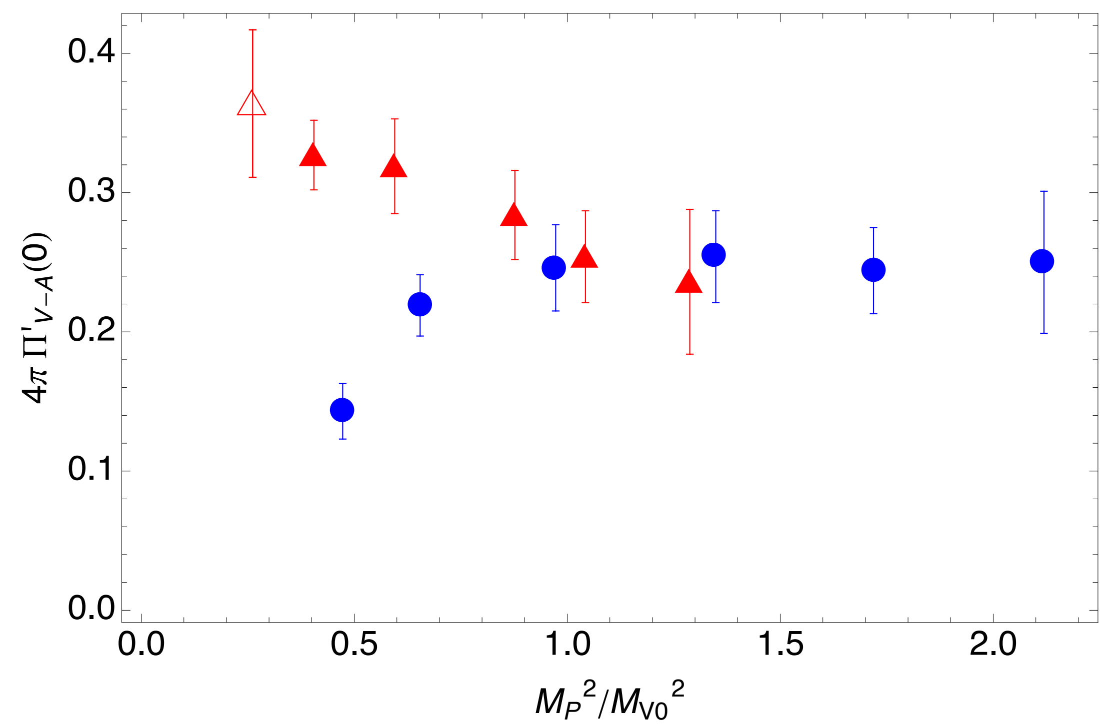
$$\boxed{\Pi_{V-A}(q^2) = \frac{\sum_m a_m q^{2m}}{\sum_n b_n q^{2n}}}$$

Correlator fits

(m=1, n=2)



$$\Pi_{V-A}(q^2) = \frac{\sum_m a_m q^{2m}}{\sum_n b_n q^{2n}}$$



Expect agreement in the quenched limit $M_P^2 \to \infty$

From slope to S

$\sim 4\pi\Pi'_{V-A}(0)$

$$S = \frac{1}{3\pi}\int_0^\infty \frac{ds}{s}\left\{(N_f/2)\left[R_V(s) - R_A(s)\right]\right.$$
$$\left. -\frac{1}{4}\left[1 - \left(1 - \frac{m_h^2}{s}\right)^3 \Theta(s - m_h^2)\right]\right\}$$

ref. Higgs mass;
we take $m_h \equiv M_{V0}$
(=1 TeV, roughly)

Standard model subtraction:

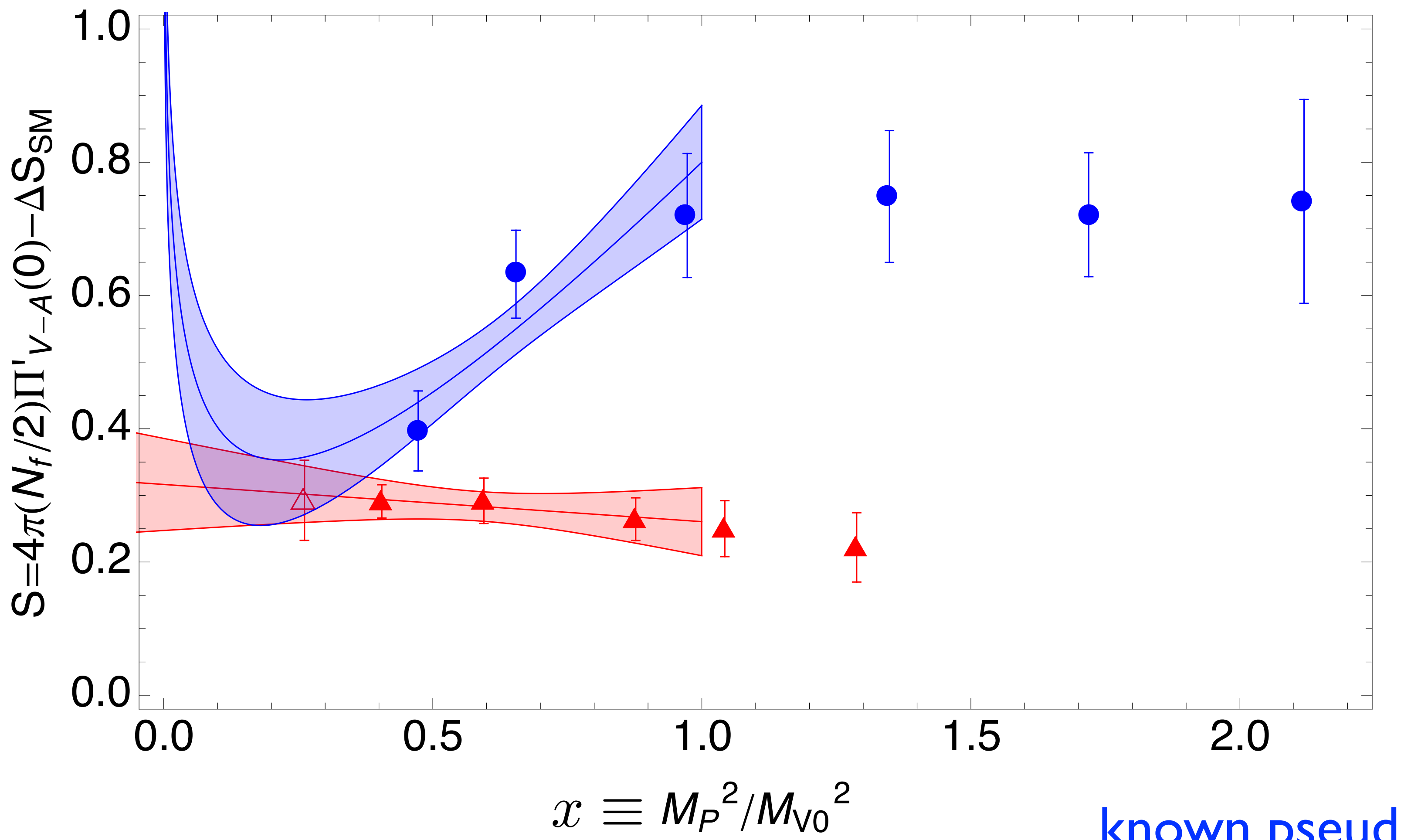
- Removes the contribution of standard model Higgs doublet to S
- IR divergent - cancels precisely with divergence in the spectrum!

$(H, \phi \to \pi_T)$

Integrate: $$\Delta S_{SM} = \frac{1}{12\pi}\left[\frac{11}{6} + \log\left(\frac{M_{V0}^2}{4M_P^2}\right)\right]^*$$

$*\left(\frac{M_{V0}^2}{M_P^2} < 1/4\right)$

From slope to S

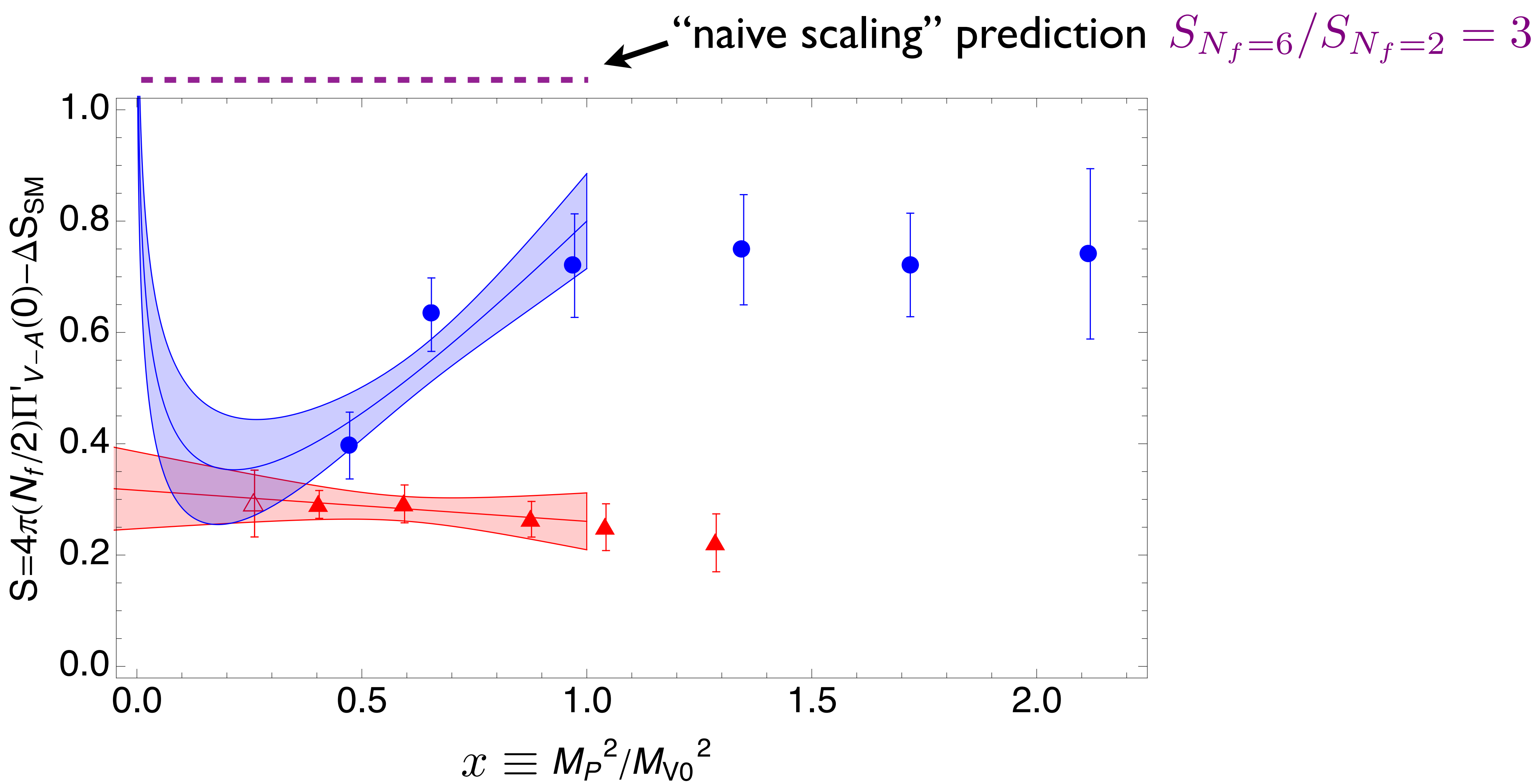


known pseudo-NGB contribution

Simple linear fit: $$S(x) = A + Bx + \frac{1}{12\pi}\left(\frac{N_f^2}{4} - 1\right)\log(1/x)$$

At two flavors, S(m=0) = 0.35(6) - consistent with other results

From slope to S



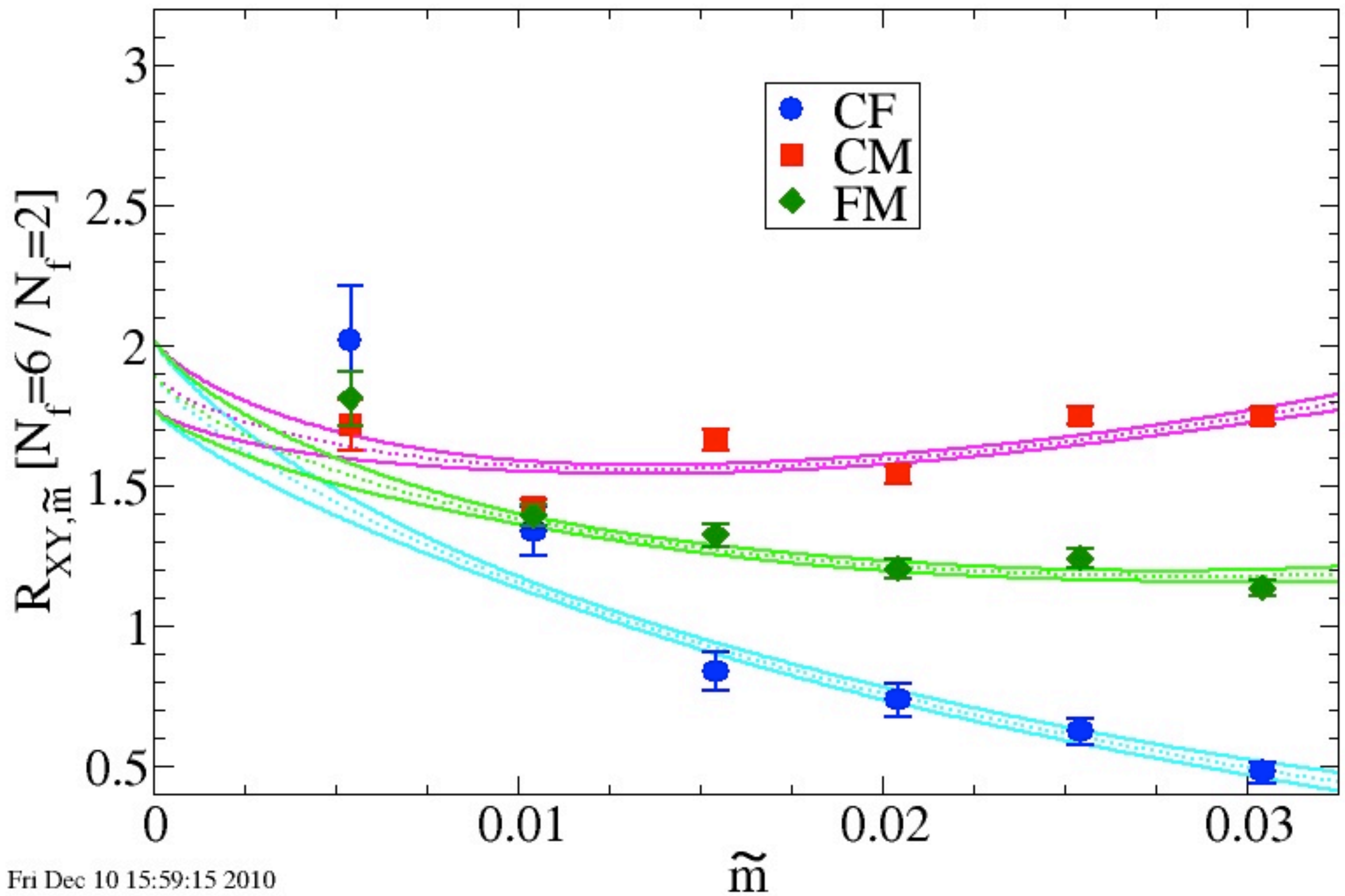
- N_f=6 result is much smaller than naive scaling predicts! (But still much too large compared to experiment.)
- This is a “worst-case” S, assuming a model with all techni-doublets EW charged.

Conclusion

- Smaller S-parameter than expected for N_f=6 theory, compared to N_f=2
- Hints of dynamics unlike QCD, effects in the right direction to reduce tension with precision experiment in EWSB models
- Simulations underway at Nf=8, 10; initial setup for SU(2) gauge group started

Backup Slides

Condensate Enhancement



Lattice scheme: $R^{(6)} = 1.95(12)$

Renormalized: $R^{(6)}_{\overline{\mathrm{MS}}} = 1.60(10)$

Pert. theory est: $R^{(6)}_{\overline{\mathrm{MS}},pt} \lesssim 1.15$

(at 3.85 GeV!)

Simulation Details

- We use domain wall fermions to preserve as much chiral, flavor symmetry as possible. Residual χSB is small:

$$m_{res} = \begin{cases} 2.6 \times 10^{-5}, & N_f = 2 \\ 8.2 \times 10^{-4}, & N_f = 6 \end{cases}$$

- All volumes are 32^3x64, lattice spacing tuned to $a \sim 5m_\rho$. At 2-flavors, this gives $a \sim 0.06 \text{ fm} = 3.6 \text{ GeV}^{-1}, L \sim 1.8 \text{ fm}.$

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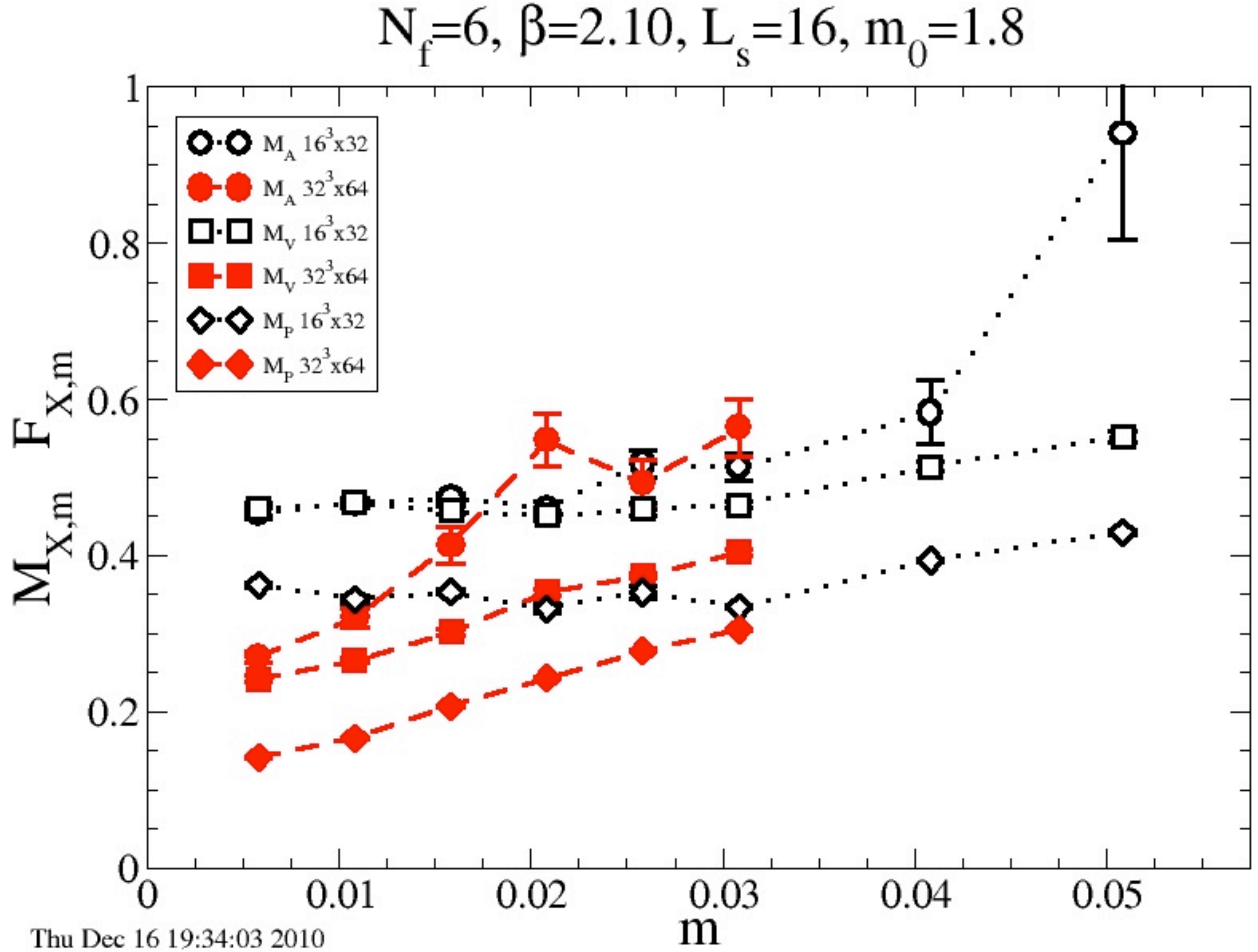
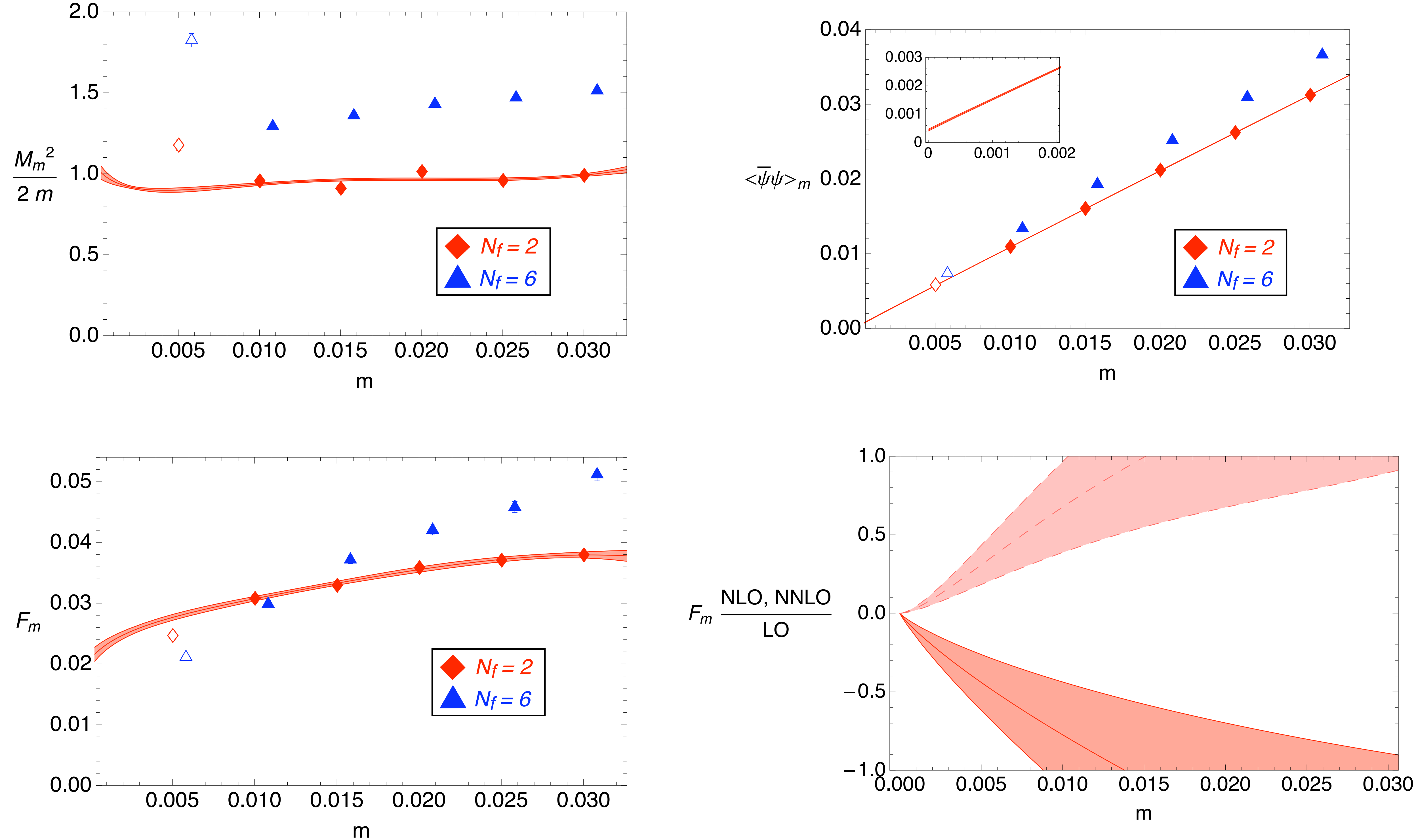
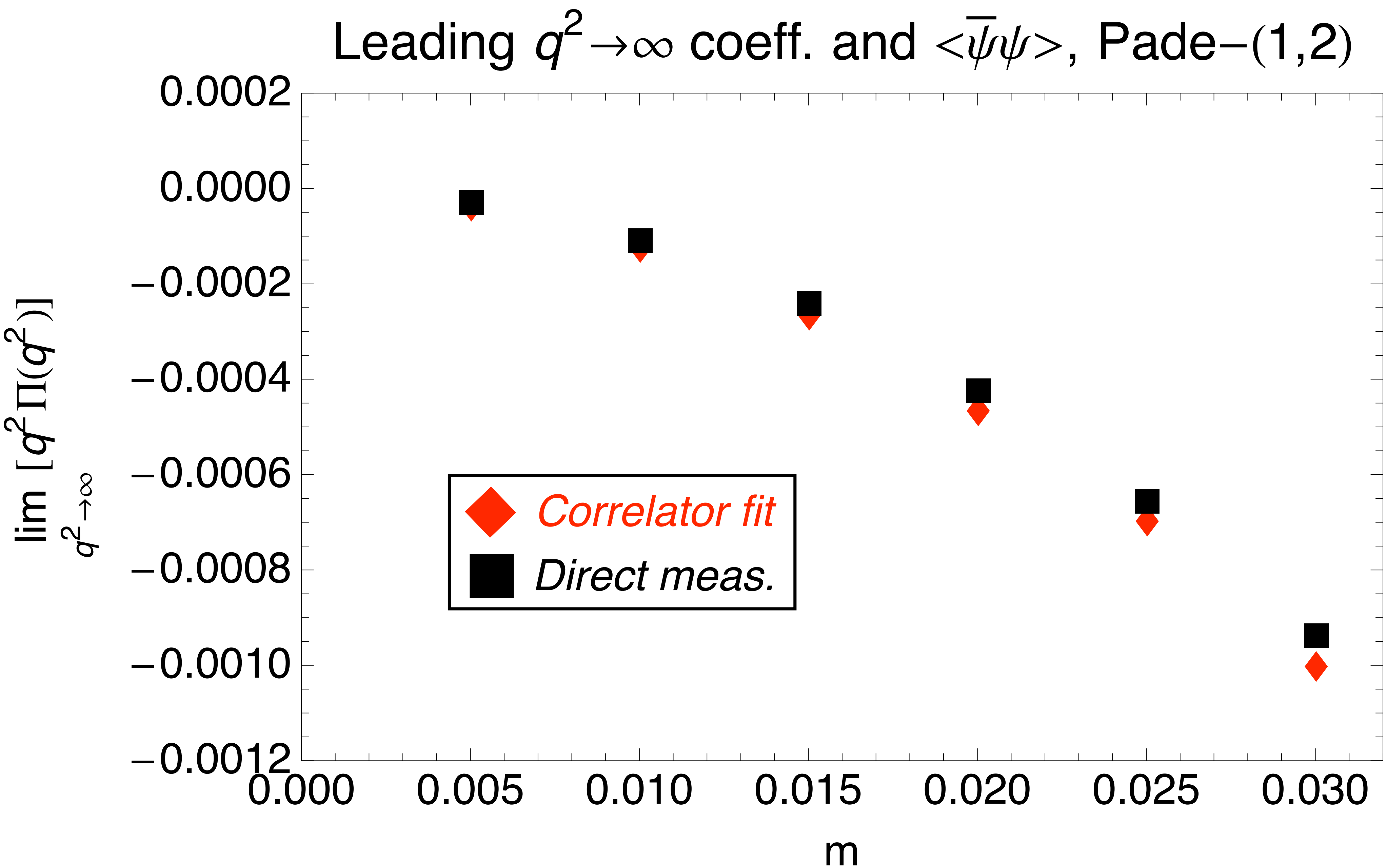
Finite-Volume Effects?



NNLO chiral fits



Momentum dependence



Excellent agreement between direct measurement and OPE